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PART II: *Science and the Future of Mankind (Jubilee Session)*

Part I

SCIENCE FOR MAN
AND MAN FOR SCIENCE

CONTEXT, ESSENTIAL CONTENTS OF, AND FOLLOW-UP TO, THE WORLD CONFERENCE ON SCIENCE HELD IN BUDAPEST IN JUNE 1999

WERNER ARBER

The World Conference on Science (WCS) was jointly organized by UNESCO and ICSU and it was held in Budapest from June 26 to July 1, 1999. Let me recall that ICSU stands for 'The International Council for Science'. On the one hand, it is a world-wide, non-governmental organization grouping, with 25 international scientific unions representing all the different disciplines of the natural sciences and mathematics. On the other, it has nearly 100 national or regional members, mostly Academies of Science with a largely interdisciplinary composition. The Pontifical Academy of Sciences belongs to this latter category of ICSU membership.

While the international scientific unions promote science at the level of specific disciplines, ICSU does so at the level of interdisciplinarity. Together with various partner organizations such as UNESCO, ICSU promotes world-wide co-operation in scientific investigations on issues of common interest by initiating and supporting special programmes. A good example is the World Climate Research Programme (WCRP). Through its multitude of co-ordinating activities, ICSU reaches a large number of scientists throughout the world. It was thus an ideal partner for UNESCO in the planning and holding of the WCS.

The aim of the World Conference on Science was to reflect on the conduct of science, its methods, its applications, and its various interfaces with human society. Therefore the WCS differed very much from normal scientific congresses with their practice of presenting recent results and discussing new ideas.

The WCS was structured into three subsequent forums. One full day was devoted to Forum I in which science and its methods were defined and the importance of international co-operation and scientific education was emphasized. This gave rise to the presentation of examples of recent advances in scientific knowledge and to an evaluation of the value of such knowledge for humanity.

Another day was devoted to Forum II in which various aspects of the interface of science with society were illuminated, such as the public perception of science, the impact of science on development, on the economy, on future generations, and on sustainability.

The WCS was attended by a total of about 2000 delegates, political leaders, scientists, and representatives of many other groups of society. Parts of the sessions were plenaries, others were split into parallel thematic meetings in which suitable time was reserved for discussions.

The three last days were made over to Forum III in which national and other delegations were allotted time to present their views on the relevance of science and its application for human society and more specifically for those nations which were represented. Although some critical voices were raised in this session with regard to some of the impacts of science, a large majority of votes were clearly in favour of a firm commitment to science and its value for the development of human society.

The generally frank and open-minded atmosphere encountered throughout the WCS might have something to do with the propensity of scientists to inter-communicate. Let me explain what I mean. Most objects of study in the natural sciences are of a global nature. Physical and chemical properties of matter are of the same nature everywhere on the planet and possibly in the universe. Similarly, major characteristics of life are shared by all organisms on all continents and in the oceans. For this reason, scientists have the habit of discussing the results of their research with each other world-wide, independently of their place of work. This communication facilitates the progress of scientific knowledge and it has the side effect of strengthening mutual trust and establishing links of personal friendship between the discussion partners. It is well known that in the practice of science, differences in opinion are not solved by fights, but by experiments and data collection, which can reveal the scientific truth. Therefore, world-wide scientific intercommunication and co-operation can have lasting effects on the establishment and stabilisation of peace, and this on a global scale.

Another interesting aspect of the conduct of science was discussed at the WCS – that of the social contract which exists between the world of science and society. Few people may be aware of this, but this social contract results from the fact that the bulk of acquired scientific knowledge serves society through helping the practical and philosophical application of available knowledge. At the WCS this long-term contract was frequently addressed, and one thus spoke of a renewal of this social contract. It is based both on mutual trust and on expectation. Society expects scientific knowledge to find applications which work to the general benefit of society, throughout the world, and scientists expect a general recognition of the cultural relevance of their work and they thus also expect the required support.

It is in this context that during a plenary session of the last day the WCS accepted by consensus two well prepared texts, one entitled 'declaration on science and the use of scientific knowledge' and the other 'science agenda – framework for action'. It is difficult to summarize these already condensed documents which deserve to be carefully read in extenso.[1] Besides explaining what science is and what its cultural contributions are, the documents represent a kind of list of rights and duties of the world of science, as well as of society in relation to science. The 'framework for action' bases its recommendations on the 'declaration' and it challenges all the partners to become seriously engaged in follow-up activities. This, of course, also concerns the Pontifical Academy of Sciences.

In the meantime both the 'declaration' and the 'framework for action' have been presented to, and adopted by, the general assembly of ICSU. More recently they have also been adopted by the general assembly of UNESCO. They have thus become binding documents. Such established engagements between society and the scientific community did not exist before the WCS.

I may mention that at the general assembly of ICSU in Cairo this fall the statements on traditional knowledge in the WCS documents were criticised, and the scientists were invited to reflect on the correct interpretation of these statements. In contrast, the major parts of the contents of the adopted documents are straightforward and free of ambiguity.

Many of the follow-up activities to be given to the WCS will concern the practical application of acquired knowledge. This may often lead to new or newly-adapted technologies in support of human welfare and commodities. Other applications may, instead, help to improve the sustainability of the environment and a more responsible use of available resources.

To finish, let me reflect on the already mentioned philosophical or

[1] Science International, Special Issue on the World Conference on Science, September 1999, ICSU Secretariat, Paris.

world-view dimensions of acquired scientific knowledge. I will do this on the basis of an example chosen from my personal field of research in microbial genetics. According to the Darwinian theory of evolution, biological evolution depends on genetic variations, on natural selection exerted on populations of variants, and on geographical and reproductive isolation. In most textbooks on evolution, genetic variants are said to result from accidents and errors. However, a critical reflection on available data on the molecular mechanisms of the spontaneous formation of genetic variants in bacteria indicates that this is only a minor part of the truth. Many genetic variants are, instead, brought about by the action of specific bacterial enzymes, the products of genes located in the genomes of the micro-organisms. These genes are called evolution genes as I outlined in more detail at the Plenary Session of the Pontifical Academy of Sciences of 1996.[2] The gene products referred to here are actually variation generators and they work both inefficiently and non-reproducibly. A well studied example is the transposition of mobile genetic elements which – under the influence of an enzyme called transposase – can undergo a translocation with the DNA molecules of the genome.

Another class of evolution genes controls the frequency of genetic variations by keeping this frequency low and at a tolerable level which can ensure a certain degree of genetic stability of a species. An example of this kind of gene action is found with the systems of repair of genetic alterations on DNA which may indeed be brought about by damage caused by a mutagen or also by the properties of the limited molecular stability of nucleotides.

This novel notion of the existence of specific genes serving primarily biological evolution would deserve deeper philosophical reflection. Let me just make a few relevant remarks. First, the coexistence in the same genome of genes for products responding to the needs of biological evolution and of more classical genes responding to the needs of each individual life merits particular attention. Second, the occurrence of genetic variation generators working both inefficiently and non-reproducibly may call for a reflection on the definition of genetic determination. This may also be relevant for genes other than generators of variations in the nucleotide sequences of genomes. A more realistic definition of genetic determination may have a

[2] W. Arber: "The Influence of Genetic and Environmental Factors on Biological Evolution", in Plenary Session, The Pontifical Academy of Sciences, on "The Origin and Early Evolution of Life" (Part I), *Commentarii*, 4, N. 3 (Vatican City, 1997), pp. 81-100.

deep impact on the public perception of the feasibility and impact of genetic manipulations. Third, while nature itself takes care of the steady evolution of life and has developed specific genes for this purpose, biological evolution is not strictly directed towards a specific goal. Rather, the direction which evolution takes depends on the life conditions encountered by the populations of organisms and on the occurrence of more or less randomly produced genetic variants in these populations. The underlying process of a steady dialogue between living beings and their environment is as a matter of fact natural selection.

It is my hope and conviction that the progress of scientific knowledge will continue to provide to all human beings on this planet both the technological and the material help to satisfy the daily needs for a life in welfare as well as a deeper understanding of the basic rules and laws of nature including its evolution. Such insights may help us in our cultural evolution to safeguard biodiversity and to ensure the sustainability of the foundations of life. These are the general goals of the social contract which was renewed between the scientific community and society at the World Conference of Science.

TECHNOLOGY: BETWEEN SCIENCE AND MAN

PAUL GERMAIN

As its title suggests, our meeting is concerned with the mutual interactions between man and science. In the present paper it is argued that between these two factors there is a new and very important entity which should also be considered and examined. 'Man', 'science' and 'technology' are very abstract words whose meaning must be made clear when they are employed. The term 'man' here refers to persons and individuals as well as to societies composed of men and women. The word 'science' (in the singular) will cover in this paper the set of disciplines which are represented within our Pontifical Academy of Sciences. The word 'technology', a singular also, will cover a great variety of different forms of technology. It is important to make a clear distinction between sciences and technologies and between technologies and techniques.

Sciences conduct research to develop, for the benefit of mankind, knowledge about the world, the earth, matter, and living beings on the one hand, and knowledge to be applied by technologies and by industrial activities on the other.

Technologies involve everything that is needed to create and produce goods, tools, things, all of which are generally very complex and which give men and women as well as societies the possibility to improve their lives and to achieve sustainable development. Moreover, they contribute to the progress of sciences because of the new kinds of apparatus and materials they provide. They reach their goals by using various results and knowledge worked out by science and techniques, but also by taking account of many constraints such as economic and financial conditions, market opportunities, production delays, prices, social acceptance, aggressive competition and so on. A technique is a skilled method by which to realise a performance or an object.

Sciences and technologies are different. Their ambitions are not the same. Sciences through research try to *discover* knew knowledge; technologies try to *innovate* and create new products. Time does not play the same role in relation to both. Competition in sciences has nothing like the decisive importance it has in technologies. To be successful, a technological activity requires the co-ordination of many actors, usually the application of many scientific results and many techniques. Very often a scientific discovery has a single author.

Obviously, scientific results play a crucial role in the success of a technology. This is why very often technology is seen as belonging to science. This seems to be the case in the principal document issued by the 'World Conference on Science' which took place in Budapest last June entitled: 'Declaration on science and of the use of scientific knowledge'. This is also probably the case in the title of the present meeting. An attempt will be made to show that one must make the distinction if one wishes to analyse in some detail the relations between the sciences and society.

1. Science and Powers

Our century has seen the emergence and the boom of technologies as a result of powerful and often multinational enterprises whose goal is specifically to make themselves always better, always more efficient, always more attractive. Thanks to these enterprises, the advance and the expansion of technologies has played the leading role in the recent evolution of our societies. Elaborate discussion is not required to be convinced of this point: military power was stimulated by the two World Wars and by the Cold War; economic power, biomedical power, communications power – all three have been very strong during the last decades; and, of course, there is also political power. These powers are very beneficial to societies because they provide them with security, sources of wealth and energy, health, the possibility to travel easily to every part of the world; they free humankind from arduous work and give the public easy access to all cultural goods. As scientific knowledge is absolutely necessary for the development of technologies, science may be rightly credited with being responsible for a large number of these important results. But, conversely, with the expansion of technologies, these powers have also brought about environmental degradation and technological disasters. They have contributed to social and even international imbalance and exclusion. The public is beginning to be anxious and afraid. In addition, science is often seen as responsible for these troubles and its image is negatively affected. That is what happens if one does not want to make a distinction between science and technology. In this situation, as the 'Declaration of Budapest' makes clear, the solution has to be found through a dialogue between the scientific community and decision-makers through democratic debate. An attempt must be made to show that to be realistic, such a statement requires a certain clarification and analysis of the respective roles of science and technology.

2. Science and the Progress of Knowledge

It is necessary to emphasise that the development of scientific knowledge during the last three centuries has tremendously enriched the culture of men and women; as well as the cultures of societies. Culture is what allows each person to understand himself, understand his relations with his environment and with other people, and his roots in the past generations, and to find, in this understanding, sources of fulfilment. The progress of knowledge is the result of fundamental research, research done just for the satisfaction of curiosity, which is, indeed, a fundamental character of the human spirit. *One must always stress the relevance of fundamental research for society*. Applied research is a necessary ingredient for improving technologies and these technologies are the weapons of the economic war between industrial companies and of very severe competition between arms factories. These powers try to attract the best scientists and to give financially interesting contracts to universities or to research establishments in order to stimulate the applied research that is useful for their programmes. This evolution is now so important that economists call the applied sciences developed for this improvement of technologies 'techno-sciences' and they affirm that all sciences are now becoming techno-sciences. Moreover, these companies try to patent the results of sciences which are useful to them, even sometimes results which are fundamental, and they then try to restrict the diffusion of the results. This is contrary to well established scientific tradition. This is specially true in the biomedical, in the biotechnological, and in particular in the genomic domains. Powerful firms often invest a considerable amount of money in these domains, thanks to the present policy on patents, against which scientists have not put up serious opposition. And the sums involved are far greater than is usually the case with public governmental institutions. The present economic system, which favours the creation of very powerful companies, will probably weaken fundamental research within the formal scientific sphere.

Many gifted young people hesitate today to embark on a scientific career because of the severe patenting conditions and the realities of harsh competition, rather than being attracted by the fight against the unknown in order to satisfy their own curiosity. The scientific community has to be cautious if it wants to preserve and maintain strong fundamental research. The challenge which presents itself here concerns the scientific creativity of humankind.

3. Scientific Expertise and the Practice of Democracy

We have seen that the technologies which are utilised and applied by biomedical or economic firms may be often very beneficial for the public, but they may also often cause difficulties and problems for nature and society. The political power may want to – and must in cases of doubt – receive advice when it has to take decisions concerning a special technology. It has to know what the causes are of its drawbacks or its dangers, what its consequences may be in the long term, whether it is better to ban it, and under what conditions it may be accepted. When scientific knowledge plays an important role in a technology, some scientists can be called in to take part in a committee which gives advice to the decision-makers. Engineers, economists, medical doctors, social scientists, and other suitable scientific experts, could also belong to this kind of committee. The questions that such a committee would have to answer are called today 'ethical questions'. Things are easy if these questions can be answered through the application of moral principles that are recognised by the great majority of people, such as human rights or human dignity. But things are more difficult for these experts in situations where the decision has long-term consequences and where ethical approaches are different. The political power may be tempted to influence the committee to give it answers which would enable it to justify its decision with reference to the recommendations of the committee. In such a case two drawbacks would exist. First, the experts would extend beyond their domain of competence. Second, they would impede the practice of democracy. What is called for is an instrument by which experts on 'spiritual, cultural, philosophical and religious values' could be added to the committee, in line with the recommendation of point 3-2 of the 'Introductory Note to the Science Agenda – Framework for Action', one of the documents adopted by the Budapest Conference. This 'Note' also argues that 'an open dialogue needs to be maintained with these values, and that it is necessary to recognise the many ethical frameworks in the civilisations around the world'. It is a pity that the principal document of the conference, the 'Declaration on Science', did not follow this recommendation. Of course such a project would be difficult to implement. But one must try. Some attempts at consensus have been made

4. Science for Development

Obviously enough, progress in technologies, and in biotechnology in particular, may be very useful for developing countries. The documents issued by the Budapest Conference provide good analyses and good recommendations. One may simply stress here that the scientific community has to meet the needs and the expectations of these developing countries. It must be careful, and must avoid the temptations offered by big firms which are more interested in the money they may earn than in social acceptance by the local populations. Methods which are good for developed nations are not necessarily the best ones for helping poor countries. During the last three days of the Budapest meeting each delegation had the possibility of giving a short address (6 minutes) to the conference. The confidence felt by the poor countries that science could solve the difficulties of their situations was very impressive. I interpreted these contributions as an appeal to more advanced scientific communities for help. I want to hope that this appeal will meet with success. The Academies of Science provided a first response a few years ago with their creation of a new institution – 'the Inter-Academy Panel on International Issues' (IAP). It is a pity that during the meeting in Budapest and in the documents issued by the conference neither the existence of the IAP nor the 'Tokyo-IAP 2000' meeting which will take place next May were mentioned. These are two recent and new initiatives which deserve to be encouraged.

Conclusion

'Science for the Twenty-First Century – A New Commitment' was the title of the Budapest meeting. With its 1800 delegates from 155 countries, it was a major success. The documents which were adopted contain many useful analyses and recommendations. What has to be new for science in the twenty-first century? What should be the new commitments of scientists?

For me, Budapest 1999 was an extraordinary occasion to re-appreciate the assignments for scientific activity. I think that two principal assignments may be proposed. The first one, the traditional one, always and for-ever, is the progress of knowledge in relation to the unknown. It has to be protected. The international body to take care of this goal is the ICSU. The second one, which is very new, is to work in favour of the harmonious and sustainable development of all the countries of the planet by ensuring that the results and the values of sciences and techniques are integrated into the culture of each individual country and that the inequalities between and within these countries are reduced. This is a new duty for scientific activity. Academies and universities are the places where this can be worked out. At the international level, the IAP, a new institution, it is to be hoped, will take care of this new responsibility.

This implies an important mutation in the behaviour of the scientific community in the advanced countries as well as in developing countries. Thus will require new forms of solidarity and fraternity between and among all the scientists of the world.

SPINNING FLUIDS, GEOMAGNETISM AND THE EARTH'S DEEP INTERIOR

RAYMOND HIDE

Astrophysical and geophysical fluid dynamics is concerned *inter alia* with buoyancy-driven hydrodynamic (HD) and magnetohydrodynamic (MHD) flows in spinning fluids, including the Sun and other stars and the fluid regions of the Earth and other planets. Such flows are dominated dynamically by the action of gyroscopic (Coriolis) forces, and they are exemplified in the case of the Earth by HD flows within the terrestrial atmosphere and oceans and by MHD flow within the electrically-conducting liquid metallic (iron) outer core, where concomitant self-exciting dynamo action generates the main geomagnetic field (1).

The most striking features of the long-term behaviour of the geomagnetic field include reversals in polarity at highly irregular intervals, ranging in duration from *ca.* 0.25 Ma to *ca.* 30 Ma – i.e. very much shorter than the age of the Earth (*ca.* 4500 Ma) but very much longer than the time (*ca.* 0.01 Ma) taken for each reversal to occur. During the past *ca.* 400 Ma there have been two so-called 'superchron' intervals, namely the Permian Superchron from *ca.* 290 Ma to *ca.* 260 Ma ago, when a magnetic compass would have pointed south, and the Cretaceous Superchron from *ca.* 110 Ma to *ca.* 80 Ma ago, when the polarity was the same as it is now (2).

Self-exciting dynamo action involves the amplification of an infinitesimal adventitious magnetic field by the essentially nonlinear process of motional induction. Yet another generic nonlinear process in self-exciting dynamos is the re-distribution of kinetic energy within the system by Lorentz forces (3, 4). Such forces operating within a self-exciting Faraday disk homopolar dynamo loaded with a nonlinear motor can quench the large amplitude fluctuations, some highly chaotic, that would otherwise occur, thereby promoting persistent steady dynamo action (after initial transients have died away) over a very wide range of conditions, with no reversals in the direction of the dynamo current and hence of the magnetic field (3).

This recently-discovered process of nonlinear quenching could be of general theoretical interest in the investigation of nonlinear dynamical systems. If it occurs in the MHD geodynamo then it would provide a firm basis for understanding superchrons as well as other salient features (such as polarity reversal chrons and sub-chrons and polarity excursions) of the long-term behaviour of the geomagnetic field (4). According to this new hypothesis – which has implications for intensity fluctuations of the palaeomagnetic field and could also be tested in due course by analysing the kinetic energy spectrum from the output of valid numerical geodynamo models (5, 6) – those eddies in the core that are driven mainly by Lorentz forces play a crucial role in the inhibition of polarity reversals. Also crucial – and testable – is the possible role in the stimulation of reversals played by changes on geological time scales in the lateral boundary conditions prevailing at the core-mantle boundary (CMB) – where the liquid outer core meets the overlying 'solid' mantle – brought about by very slow convection and other dynamical processes affecting the lower mantle (1, 4, 7, 8). Coriolis forces due to the spin of the Earth would render the patterns of core motions, and of the magnetic fields they produce, very sensitive to modest lateral variations in the physical and chemical conditions at the CMB, which techniques of seismology, geodesy, geochemistry, etc. might in due course be capable of resolving with acceptable accuracy (7, 8).

Geodynamo studies thus facilitate the exploitation of a wide range of data in research on the structure, dynamics and evolution of the Earth's deep interior, about which much remains to be learnt (notwithstanding the great success of the theory of plate tectonics in the investigation of the *outer* layers of the Earth). As in other areas of astrophysical and geophysical fluid dynamics (e.g. dynamical meteorology and oceanography), such work is impeded by the intractability of the governing nonlinear *partial* differential equations expressing the laws of dynamics, thermodynamics and (in the case of MHD) electrodynamics – compounded in this case not only by the lack of detailed geomagnetic observations covering long periods of time but also by the technical difficulties of carrying out laboratory experiments in MHD. So thorough investigations of much simpler but physically realistic self-exciting dynamo systems governed by nonlinear *ordinary* differential continue to play an important if indirect role in studies of the Earth's deep interior.

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RECENT DEVELOPMENTS AND CULTURAL ASPECTS

YURI I. MANIN

For the purpose of this presentation, I will roughly divide mathematics into four large areas: fundamental mathematics, mathematics as the language of theoretical physics, mathematical modeling, and mathematics of modern information and communication technology (computers and networks). This subdivision reflects differences in values more than in content, but exactly for this reason it is relevant for our discussion: science for man and man for science.

1

Fundamental (or pure) mathematics deals with elaborate and subtly interwoven abstractions some of which date back to the ancient Greeks and of which some keep appearing in new issues of mathematical journals. As an example, consider Euler's famous formula $e^{\pi\iota} = -1$. In an extremely concise fashion, it relates three mathematical constants whose respective discoveries were separated by centuries and motivated by very different lines of thought.

In fact, $\pi = 3, 1415926$ is essentially a physical constant distilled to a mathematical notion in Euclidean geometry, which itself can be viewed as a physical theory: kinematics of solid bodies in a gravitational vacuum. Unlike π, the base of natural logarithms, $e = 2, 718281828$, first appeared in the great project which later became computer science, whose purpose was to facilitate time consuming numerical multiplication by replacing it with addition. Finally, the imaginary unit, $i = \sqrt{-1}$ kept emerging, almost against the will of its creators, as an inscrutable but vital fragment of the formal system of algebraic notation, without which it would lack a degree of logical completeness. Euler's formula was a small wonder demonstrating the heuristic power of the recently invented calculus.

As in Euler's time, the proof of a difficult theorem, the solution of an old problem, the formulation of a striking conjecture expressing an insight into an unexplored field, are all important aspects of pure mathematics. Practitioners of pure mathematics teach at universities and pursue their research in a handful of world centers established for this purpose. They constitute a small community in each generation, whose public image, eloquently described by Hans Magnus Enzensberger, is that of insularity and detachment ([E]).

2

As the language of theoretical physics, mathematics enjoys an unusual epistemological status. The point is that the initial semantics and syntax of many mathematical notions often have nothing to do with the secondary semantics which they acquire in the context of a physical theory.

Consider an example: complex numbers and their role in quantum mechanics as "probability amplitudes". Euler's formula, mentioned above (or rather its generalization $e^{i\varphi} = \cos \varphi + i \sin \varphi$), in the context of quantum mechanics explains quantum interference and becomes the quintessence of the wave aspect of the famous wave/particle duality. The imaginary unit, and complex numbers in general, cease to be purely logical constructs and acquire a physical incarnation as quantum phases. They become as "real" as real numbers in the sense that their effects can be experimentally observed and measured. And π in Euler's formula this time does not refer to the angular measure in the Euclidean plane, which is after all only an idealized sheet of paper, but to the considerably more abstract complex plane of quantum phases.

In this way, theories developed in pure mathematics and having their intrinsic logic, are periodically reinterpreted as models of basic physical phenomena. In the last third of this century, this happened to topology and algebraic geometry with the advent of quantum strings, membranes and the project of Grand Unification in the framework of the emerging *M*-theory. Such unpredictable applications are often quoted in order to motivate and justify public spending on pure mathematics. In turn, physics has a profound influence on the development of mathematics. I mention only the recent successes of Feynmann's path integration in topology.

The community of physicists has grown enormously in this century, partly because of military applications, but it is not a purely modern phenomenon. It suffices to recall that Archimedes was a military engineer, and probably, if recognized and captured alive, would have had to work for Romans as Werner von Braun did for the Americans two millennia later.

3

I have set apart mathematical modeling from both pure mathematics and theoretical physics mainly because these activities differ in the minds of those who participate in them. This is discussed at some length by D. Mumford ([M]), who writes: “Models are most prominent in applied mathematics where they express the essential point at which the chaos of experiment gets converted into a well defined mathematical problem”. Galileo’s famous definition of mathematics as the language of nature was based on his experience of such conversion rather than on the fancier mathematical models that emerged later and have a more Platonic flavor.

The distinction between the models used in applied sciences and those of fundamental physics is debatable. In fact, such constructs as the Ising model show that there is no clear-cut boundary between the two. I feel nevertheless that there exists a qualitative difference between, say, the principle of superposition of quantum mechanics (which is a fundamental law) and Hooke’s law stating linear dependence of force as a function of displacement (which is only a convenient model).

More to the point, mathematical model-building includes the vast domain of models in Economics: gathering, processing and distilling statistical data into viable theoretical schemes which often enjoy explanatory and predictive force, but clearly have nothing really fundamental about them. As Mary Poovey convincingly argues in [P], this line of development, starting with Luca Pacioli’s double-entry bookkeeping, informed not only the external forms of modern economic life, but to a considerable degree also the perception of reality and even the self-perception of Western society. Poovey coined the term “modern fact” to express this notion, and thoroughly studied it in her book.

Model-building acquired a new dimension and a large new community of customers with the advent of computers. Perhaps, the most important trait of it is now the option of doing a considerable part of theoretical work by running a program (computer experiment), and/or compiling a vast database (like human genome project). Mathematics of materials (e. g. composites) or models of vision may serve as examples of scientific applications of mathematical modeling.

4

The modern industry of computers and communication networks is the technological embodiment of the abstract mathematical development dealing with the microstructure of information and information processing. The history of this development again spans two millennia, from Aristotle's classification of syllogisms to Turing's machine.

Somewhat paradoxically, with the advent of personal computers and Internet this has become the most visible and most widely used mathematical product. Moreover, user-friendly technological solutions allow one to become a customer of such a system without being burdened by knowledge of mathematics, much in the same way as we drive cars without having to understand thermodynamics and the kinetics of internal combustion.

As I have tried to show, mathematics supported many processes which were vital for the development of modern society and which determined its present state. This role of mathematics raises various issues which I will present in the same order in which I have discussed the sociology of the mathematical community.

5

Pure mathematics traditionally was regarded as a part of high culture, on par with, say, philosophy and music. Edna St. Vincent Millay's line, "Euclid alone has looked on Beauty bare" only a century ago was a poetical expression of commonplace wisdom. This view is now challenged by several cultural shifts.

Academia, with its traditional network of independent universities, libraries, publishing houses and its peer review system, is evolving in the direction of becoming a specialized training and research ground, a part of the service industry subject to market economy laws (especially in the USA), or responsible and directly accountable to government agencies. Consumerism generally lowers cultural standards and tends to dilute or even completely exclude from the curriculum courses requiring hard work and not leading to the immediate and materially rewarding career openings. Mathematics especially suffers from these tendencies.

Applications of mathematics to industry and biology are challenged by the New Age sensibilities. Environmentalists blame science and technology for the destructive uses we made of them, thus further diminishing their cultural appeal.

On the opposite end of the spectrum of intellectual life, deconstructionist and postmodern trends of discourse put in doubt the very notion of scientific truth, trying to replace it by highly arbitrary intellectual constructions, based upon Freudian fantasies and ambiguities of natural language. Moreover, the grand culture of European origin or cultivation is diminished in stature by such pejorative connotations as cultural imperialism and Eurocentrism.

H. Bertens in [Be] argues that postmodernism is essentially positive and compatible with left-liberal political trends, whose essence is “self-reflexivity that leads to the unmasking of prejudices and exclusionist strategies”. In particular, in his words, “culture at large becomes aware of its hierarchical structure – with white males at the top of every heap – and begins a long march, far from over, on the road to redressing all sorts of historical wrongs”.

These noble intentions notwithstanding, implications of such a mindset for science, its values and its goals, are far from being positive. In fact, they lead to a wild politization of any discourse involving science. In extreme cases they involve misrepresentations of its content and meaning (as was demonstrated by Socal and Bricmont in their analysis of some canonical postmodern texts), and even complete negation of the central notion of science, that of objective truth. As a frustrated Galileo asked in 1605, “What has philosophy got to do with measuring anything?” Four centuries after, we still seem to be unsure about the answer.

This school of thought replaces serious thinking by soul-searching and collective psychotherapy thus effectively preventing our community from seeking responsible answers to the problems of modernity.

Computers and the Internet, helping to solve some of these problems and permitting unprecedented freedom of communication, pave the road to changes, the full scope of which we cannot as yet foresee. As an example, one can cite their role in financial markets which arguably have brought us closer to the dangers of global economic instability. Other concerns are related to the whole structure of information storage and processing in modern society, which is becoming increasingly dependent on quickly mutating and obsolescent hardware and software.

Victor Hugo remarked in “Notre Dame de Paris” that books killed cathedrals (meaning that Enlightenment culture replaced medieval Christian culture). It looks now as if computers are killing books.

Let me quote I. Butterworth: “...the American Association of Computing Machinery, the main US learned society in the computing area, with 18 journals totaling 30000 pages per year, plans to stop completely its printed versions by the year 2000. It is common to hear in such societies statements like 'We want to destroy print'".

There are qualitative differences between libraries and electronic archives. On the positive side, new technology provides the speedy and universal storing of, and access to, information, including papers, books and databases; visual and sound materials; flexible electronic linking; and much more. On the negative side, the life span of the supporting hardware and software is alarmingly short: "...the hardware on which digital information is to be recorded and accessed has a typical life of 10 years" and, moreover, "to a first approximation, no one can use a piece of software written 10 years ago. [...] Maintaining an archive therefore requires expensive human involvement to ensure that, by continual re-copying and by updating of protocols, it can still be accessed. [...] Commercial publishers may be willing and even anxious to maintain archives as long as they have commercial values as databases, but would presumably then allow them to die. If research and scholarship are not to become ephemera, active archives will probably have to be maintained by a combination of learned societies and national legal deposit copyright libraries – but the operation will not be cheap" ([Bu]).

Finally, we are becoming more acutely aware of the dangerous effects of the "stupidity amplification" phenomenon, the Y2K problem being only one of its most outrageous instances.

The fate of mathematics depends on the fate of society. Mathematics was traditionally considered to be the finest expression of rationalism. We must demonstrate again and again that being rational also means being moral.

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SCIENCE AS UTOPIA

JUERGEN MITTELSTRASS

Utopias are emigrated wishes; science is a way to recover them. What do we mean when we say that science has a utopian character and is a utopia? Is not science real? Is not science an essential part of our academic life and an essential part of the modern world? In this paper I shall propose four brief theses to describe the utopian element in science and its peculiar infinity.

1. *Uncompleted Science*

Science is never perfect; it is always something that is unfinished – not in the sense of a defect, but as something that belongs to the essence of science, to its peculiar infinite character. If science were something which could be completed, that is to say, if at some point everything that can be explained with scientific methods were to be explained; if at some point all questions that can be posed scientifically were to be answered; and if at some point everything that can be mastered with scientific methods were mastered, then science itself would be a mere means, an artefact, not a process – at least not in the sense that science constitutes precisely the future potential of a technical and rational culture such as ours. It would be as if one took rationality or reason to be something which could be completed, to be something that one could at some point have at one's disposal as a perfected good. But rationality and reason are, in opposite fashion, never completely fulfilled. They are demands upon thought and action that must be constantly aroused, at least in the wake of the European Enlightenment. They are demands whose sense lies not in their complete realisation but rather in their 'infinite' contribution to orientation.

This is the case, too, with science. In science we find expressed the 'infinite' will of man to comprehend his world – and himself – and even more to make it his own work. That this, too, in turn, is an infinite task lies not in the fact that this task itself is utopian – we already live in a world which is to an ever increasing extent the product of scientific and technical understanding – but rather in the fact that there are no scientifically final answers to the question of how the world of man, insofar as it is (also) his product, should look in the end, and how mankind, even with scientific means, should understand itself. Furthermore, science is extremely inventive, not only in its results but also in its questions, and it is inexhaustible, just as understanding and reason are inexhaustible. 'Science as Utopia' is an expression of this 'infinity' of science or of a scientific culture, and it is the expression of the insight that science – again, like understanding and reason – always has its essence ahead of it, that is to say it always lives in the awareness that it is not what it is supposed to be, namely – in the words of the German Idealist Fichte – absolute knowledge. Such knowledge is indeed a pure utopia, but a useful one: it keeps the process of science and the process of knowledge in general in motion.

2. *Transdisciplinarity*

The scientific spirit is in motion – not only along the usual paths of research but also with regard to its own disciplines. Disciplinary orderings are increasingly replaced by transdisciplinary orientations. Transdisciplinarity means that research is to a great extent in motion out of its disciplinary limits, that it defines its problems independently of disciplines and solves them by passing beyond these boundaries. The institutional expressions of transdisciplinary orientations – which are effective wherever a strictly disciplinary definition of problem situations and problem solutions no longer fits – are the new scientific centres that are being founded or have already been launched, such as the Harvard Center for Imaging and Mesoscale Structures or the Stanford Bio-X Center. These centres are no longer organised along the traditional lines of physics, chemistry and biology institutes or faculties but rather from a problem oriented perspective, which in this case follows the actual development of science. Transdisciplinarity proves to be a promising new research principle. Where it is in place, the old institutional structures begin to look pale. Research is looking for a new order.

The development of science in a transdisciplinary direction may even reawaken the notion of a *unity of science*, which during the development of modernity replaced the older notion of the unity of nature. But this notion of a unity of nature seems also to have gained ground once again (in science and philosophy), at first as the conception of a unified physical theory – if there is only one nature, then all natural laws must also be part of a unified theory of nature – then in the form of increasingly transdisciplinarily-oriented scientific research. If nature does not distinguish between physics, chemistry, and biology, why should the sciences that study nature do so in a rigid, disciplinary manner?

The unity of science and the unity of nature may well be philosophical dreams, but their basis – ever more strongly integrative, indeed, transdisciplinary research – is real. Some examples are: (1) nanotechnology, in which physicists, chemists and biologists work hand in hand in the production and investigation of nanostructures; and (2) foundational questions of quantum mechanics, which are worked on in cooperation by physicists with very differing backgrounds, especially mathematical physicists and researchers in the field of theoretical and experimental quantum optics, and by information scientists and philosophers; but also (3) monistic and dualistic explanatory conceptions within the framework of solving the so-called mind-body problem, in which originally purely philosophical approaches are connected with research in neurophysiology and neuropsychology into the empirical connections and mutual dependencies of physical and psychical states and processes. Transdisciplinarity is constantly reinventing science – and in this way it remains close to science's 'infinite', and thus also always utopian, essence.

3. *The Limits of Science*

There is scarcely a place where the unfinished, 'infinite' or utopian character of knowledge and of science is made more clear than in the question of the *limits of knowledge and science*. It is all the same whether *practical* limits are meant, that is, limits presented by our comprehension and the means it has at its disposal; *moral* limits, that is, limits that place knowledge acquisition and science under ethical categories; or *theoretical* limits, that is, limits that cannot be overcome – independently of practical and moral limits. Here we are concerned with the question of a *de facto* finitude, which would connect the utopian with knowledge and science, this time in a negative sense.

The philosophy of science discusses this question, usually with reference to the natural sciences, in the form of two theses. (1) The thesis of the complete or asymptotic *exhaustion of nature*. According to this thesis, the history of scientific discovery is either absolutely finite or at some point goes over into an asymptotic approximation to what can be known. The place of innovations would be taken by filling-out and mopping-up operations, the calculation of additional decimal points, and the classification of additional cases, which tell us nothing that is essentially new. (2) The thesis of the complete or asymptotic *exhaustion of information capacities*. According to this thesis, the scientific information possibilities are either again absolutely finite or at some point go over into an asymptotic approximation to absolute limits of information. Here, too, filling-out and mopping-up operations would take the place of innovations. Science would have exhausted its own research and articulation possibilities; between it and a possibly unexhausted nature there would rise an insurmountable information barrier. The crucial question – whether scientific progress still has a future – would only be apparently paradoxical. However, within the boundaries of the two theses presented, this question is unanswerable, and this, too, speaks in favour of the infinite and the utopian in the affairs of science.

One reason for this is that *questions*, and in particular scientific questions, know no bounds – what would be the sense of saying that all questions are answered? (At best, saints could talk like this). And the *goals*, in this case goals pursued by scientific knowledge, are similar. If research is not determined only by the respective state of research already reached (for instance with regard to answering scientific questions), but also by the (internal and external) goals tied to it, then the notion of an end to scientific progress would not only include the assertion that we know everything (that we can know), but also the assertion that we know all goals (that we can have). The number of these goals, however, is unlimited even if we accept the limits ascribed to the scientific permeation of the world and of mankind. But this means that in order to be able to answer the question – whether scientific progress has a future – we would in a certain way already have to know what we do not know now, that which only scientific progress or its failure could show. In this sense there are no limits to science.

4. *The Phoenix*

What I have said about transdisciplinarity applies to scientific thinking in general: scientific thinking, so to speak, constantly invents itself anew, realises itself in its constructions and destroys itself with its constructions. The phoenix is the symbol of science just as the owl is the symbol of philosophy. Science creates itself just as philosophy constantly looks at itself and what it has seen. Science lives from the mortality of knowledge, philosophy from the immortality – or better, from the infinity – of reflection, which also constantly meets itself, while science forgets and discovers. Only the concept of construction holds the two together. For philosophical reflection, too, – as long as it does not just reproduce itself hermeneutically in a state of infertility – constructs, designs new worlds and fills them again with its grown-old experiences.

Returning once again to the beginning: if science knew everything that it could know, it would in a certain sense be perfect in its limitation and finitude, that is to say, everything that could be explained according to its own questions would be explained; everything predictable according to its cognitive base would be explicated; everything cognitively demanded according to its own epistemic intentions would be available as an instrument; and what is given with the above mentioned perfections would leave no room for other things to be explained. But this notion suffers from the above mentioned circumstances connected to the infinitude of our questions and our goals. Scientific progress is thus limited neither by an attainable perfection of knowledge nor by absolute theoretical limits of knowledge – however, there are practical limits. For the limits of science are either *limits of error* (the scientific intellect is stymied by its own insufficiencies) or *economic limits* (scientific progress becomes unaffordable) or *moral limits* that are always given whenever scientific progress turns against mankind itself. Whatever the case, every measure of science that puts limits to its progress is a practical measure and thus a self-given measure. And this, too, means that science is always essentially something unfinished: uncompleted limits and uncompleted limitlessness – the concrete utopia of science.

FROM MODERN RESEARCH IN ASTROPHYSICS TO THE NEXT MILLENNIUM FOR MANKIND

GEORGE V. COYNE

Introduction

The organizers of this meeting have requested that "the papers should take the form of sets of suggestions rather than academic lectures". I will, therefore, make two suggestions and support them by a brief review of several areas of research in modern astronomy. Among those areas I will emphasize the search for extra-solar planets and planetary systems.

Suggestions

I would like to suggest that all of our planning for the Plenary Session and other activities of the first year of the new millennium take into account the following two conclusions which can be drawn from the most recent research in astrophysics: (1) there is increasing evidence that we may not be alone in the universe; (2) public opinion to the contrary, our scientific knowledge of the universe is very limited.

We must be very careful in our formulation of the first issue. The question to be addressed is not whether there is extraterrestrial intelligence, since there is no scientific data whereby to even approach an answer. The question is rather: Are there the physical conditions for Earthlike life elsewhere in the universe? In other words, is there any evidence that there are planets like the Earth about stars like the Sun with the macrophysical conditions for life?

As to the matter of our ignorance as regards our scientific understanding of the universe, a brief review will suffice to indicate the limited frontiers of our knowledge. The most significant fields of modern astronomical research extend over a wide range of topics including the physics of the early universe to the search for extra-solar planetary systems. We shall do that review of selected topics now and subsequently speak in more detail of the search for extra-solar planets.

Selected Topics in Astrophysics. Frontiers of Ignorance

By combining elementary particle physics with quantum cosmological models we have a solid understanding of the very early universe, although not its origins. Less well known are the epochs of the formation of structure in the universe: galaxies and clusters of galaxies. Despite intense efforts to determine the ultimate fate of the universe, we do not yet know whether the mass of the universe exceeds the critical mass to close it. More than a decade of attempts to identify the dark matter in the universe have left us still in doubt, although the observational evidence for its existence is overwhelming. Let us review these topics in more detail.

The deep field observations with the Hubble Space Telescope challenge all theories accepted to date for the development of structure. A principal difficulty is that the observations indicate that structure developed much earlier than can be accounted for in any of the expanding universe cosmologies. The detection of non-homogeneity challenges inflationary models. It is not yet known with certainty as to whether galaxies formed from a single massive proto-galactic cloud or whether they formed from mergers of smaller regions where star formation had already begun. This uncertainty is fundamental and is shown graphically in the schematic diagram of the evolution of the universe in Fig. 1. The formation of galaxies at one billion years and of the first stars at five billion years is essentially unknown!

The great success of Big Bang cosmologies during this century may conceal some of the principal problems still remaining. Chief among these is the determination of the distance scale and, therefore, the time scale for the expanding universe. The Hubble law relates the velocity of expansion of the universe, determined by measuring the red-shifts of galaxies and clusters of galaxies, with distance. This is shown in Fig. 2. It is important at this point to note an observational problem associated with the Hubble law. The observational error associated with measuring a red-shift does not depend on distance, whereas the error in measuring distance increases enormously with increasing distance. For large distances we must make many assumptions about the uniformly mean brightness of certain kinds of intrinsically bright objects, for instance, supernovae or globular clusters, and we must apply assumed corrections for the aging of such objects.

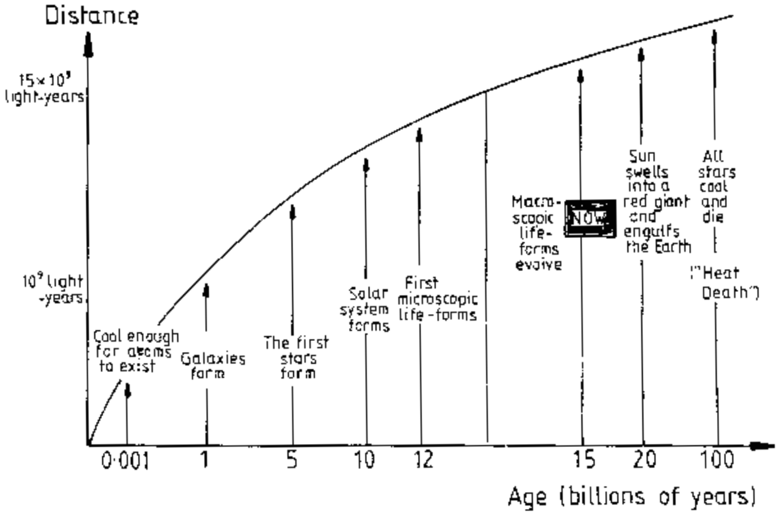

Fig. 1 – A schematic of the expanding universe. As the universe gets older (abscissa) the distances between objects increase (ordinate). The epochs at which various principal events occurred are indicated by arrows. Although shown here, we are not certain about the epochs at which galaxies and the first stars formed.

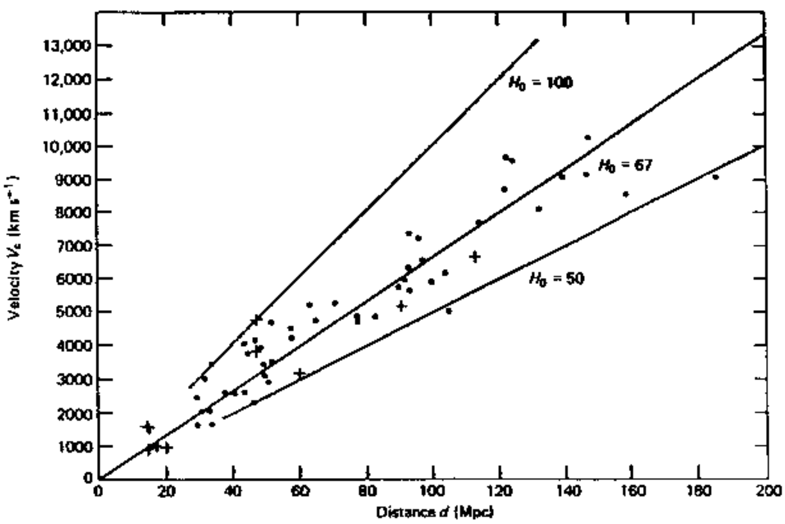

Fig. 2 – The Hubble law shows the velocity at which the universe is expanding at various distances (1 MPC [megaparsec] = 3.3 million light years). The Hubble constant, H, is the slope of the relationship and is inversely proportional to the age of the universe. The three lines show the extreme values and the mean value to the scattered observations.

The distance limit for the so-called primary methods of measuring cosmological distances is about thirty million (3×10^7) light years, only two thousandths of the way back to the Big Bang. For larger distances the observational errors result in an uncertainty in the slope of the Hubble law (the Hubble constant), which is roughly inversely proportional (a specific cosmological model with a given deceleration parameter must be assumed) to the age of the universe. Recent observations with Hubble Space Telescope (HST), for instance, indicate a change in the distance scale which would essentially decrease the currently estimated age of the universe by a factor of two. In that case we would have some globular clusters of stars, whose ages are known by methods completely independent of the Hubble law, with ages about twice that of the universe itself. A problem, indeed! It is of some interest to note the history of the determinations of the Hubble constant. The age of the universe has roughly changed by a factor of five in the course of fifty years!

Two increasingly difficult problems are the quantity and nature of dark matter in the universe and whether the universe is open or closed. The two problems are related. From the observed rotation curves of spiral galaxies and from the gravitational binding of rich clusters of galaxies, it has become increasingly clear that about ninety percent of the gravitating matter in the universe does not radiate What is the nature of this dark matter which is so predominant?

We know that the universe is tantalizingly close to being either open or closed. There are two approaches to try to resolve which is the case. If we could measure the curvature of the Hubble law at large distances, then with certain reasonable theoretical assumptions, we could resolve whether the universe was open or closed. This is shown schematically in Fig. 3. As we look at large distances, we are looking back in time and we can compare the observed expansion rate then to that in more recent times. We can, therefore, in principle, determine the rate of deceleration of the expanding universe and whether such a rate is sufficient to close the universe. The observational problem is precisely the one which we have discussed previously and is shown by the scatter of the points in Fig. 3. Errors in the measurement of large distances will not allow us to determine accurately enough which of the Hubble curves (A, B, C or D) is the true one.

Another approach to determine the closure or not of the universe is to measure the mean density of the universe. If the mean density is greater than a critical value, estimated to be about five H atoms per cubic meter, then the universe is closed. This is a very sound approach, based on the

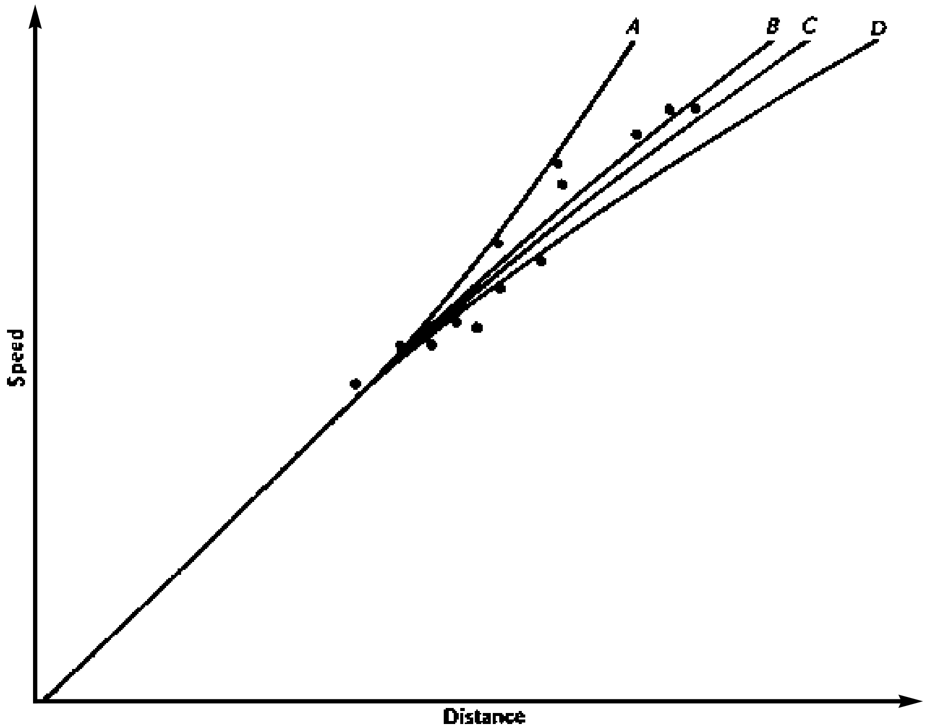

Fig. 3 – Because of the uncertainty of the Hubble law at large distances, due to increasing errors in the distance measurements, it is difficult to decide which of the curves, A, B, C or D describes the real universe. Thus, we do not know whether the universe is open or closed.

simple working of gravity, but how are we to measure this mean density when it is estimated that ninety percent of the matter in the universe is not radiating? We are left with the uncertainty as to whether the universe will end at all and, if so, whether with a crunch or a whimper.

Extrasolar Planets. Theory and Observations

The best model we have for the formation of planets about solar-like stars is shown in Fig. 4. A large interstellar cloud, typically containing 10^3 masses of the sun, fragments due to an interplay of kinetic, gravitational and magnetic energy. Each fragment that is sufficiently compact and sta-

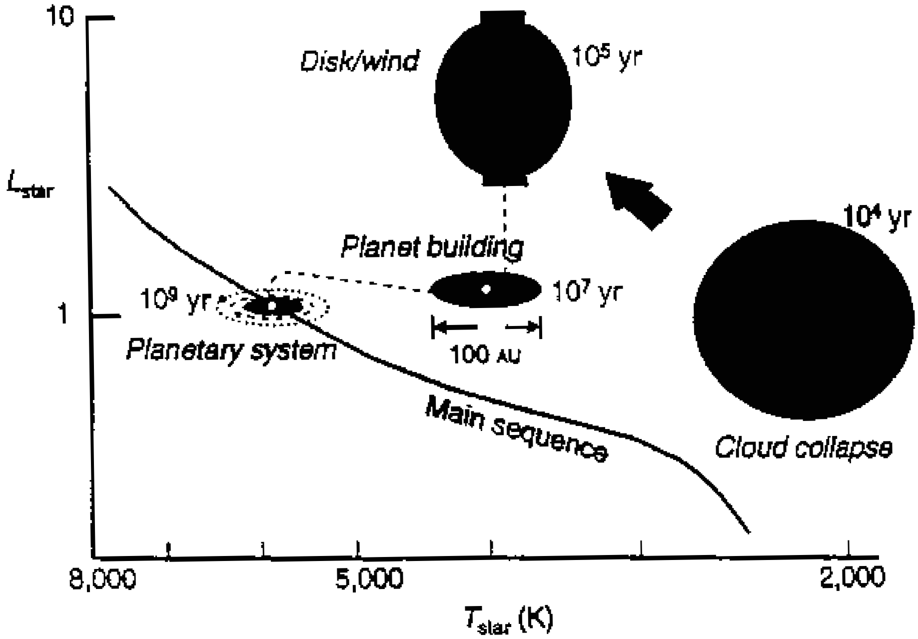

Fig. 4 – The scenario for the birth of stars and planets. See text for explanation.

ble begins to collapse by self-gravity and, like any normal gas, as it collapses it heats up. If it is sufficiently massive (more than about 0.1 the mass of the sun), it will raise the temperature in its interior sufficiently high, so that thermonuclear burning begins. At this point a star is born. (This is called a pre-main sequence star, since it is not yet completely stable.) For a star with a mass equal to that of the sun this process takes about 10^7 years. For more massive stars it is shorter, for less massive stars longer. The sun will keeping shining as it does today for about 10^{10} years and then it will explode and become a white dwarf. Note, therefore, that a star like the sun is born relatively (relating "gestation" to "lifetime") fast, some ten times faster than the birth of a human being! In the course of the cloud collapse there are stages which are important for the formation of a planetary system. As the star collapses, in order to conserve angular momentum, it rotates and this rotation cause a continuous flattening of the cloud until at the end of 10^7 years a disk has formed. There is also an intermediate stage after about 10^5 years at which a wind of high energy particles sweeps through the cloud and carries away much of the material left over from the collapse.

So, we have a solar-like star with a rotating disk of hydrogen gas and dust about it. How do planets form within this disk? As the disk continues to rotate the material in it begins to separate out into rings according to the mass distribution. Within each ring conglomerates begin to form due to elastic collisions, gravity and electrostatic binding. Eventually larger conglomerates, called planetesimals, of the order of 100 kms in extent are formed and then from these the planets are formed. During these processes the lighter elements are preferentially driven to the outer parts of the disk due to temperature of the parent star and the stellar wind. This explains why the outer planets in the solar system are more gaseous than the inner planets. Thus, for a star like the sun we have after about 10^9 years a stable star with a planetary system about it.

Patient and painstaking research over the past decade has led to the discovery of more than fifty planets about other stars. These planets have been discovered by analyzing the systematic oscillations in the motion of the parent star or, in rare cases, by the direct measurement of the displacement of the star on the sky. Examples of such measurements are shown in Fig. 5. Only massive planets near to their parent star can be discovered in this way. Jupiter, for instance, could not be detected in this way from the nearest star to the Sun. So, the method is very limited. In no case, do we have an Earth-like planet in a habitable zone. A sample of planets discovered thus far is shown in Fig. 6.

At times there is an ambiguity as to whether the object discovered is a “brown dwarf” or a true planet. If a collapsing cloud has less than about 0.1 solar masses it cannot raise the internal temperature high enough to start a thermonuclear furnace; so, no star is formed. The object still shines but not by thermonuclear energy. It has short-lived residual gravitational energy and is called a “brown dwarf”. The division between “brown dwarfs” and planets is ambiguous and it is difficult to separate out these objects. Planets form by the accretion of planetesimals; “brown stars” form like stars do by the collapse of a cloud fragment. So, the formation processes are very different; but the resultant object may lie on the observational borderline.

An increasingly fruitful area of research is the detection of proto-planetary disks about young stars. Very high resolution imaging is required and thus far only Hubble Space Telescope has succeeded. In some of the disks detected we have indications that the formation of planets has

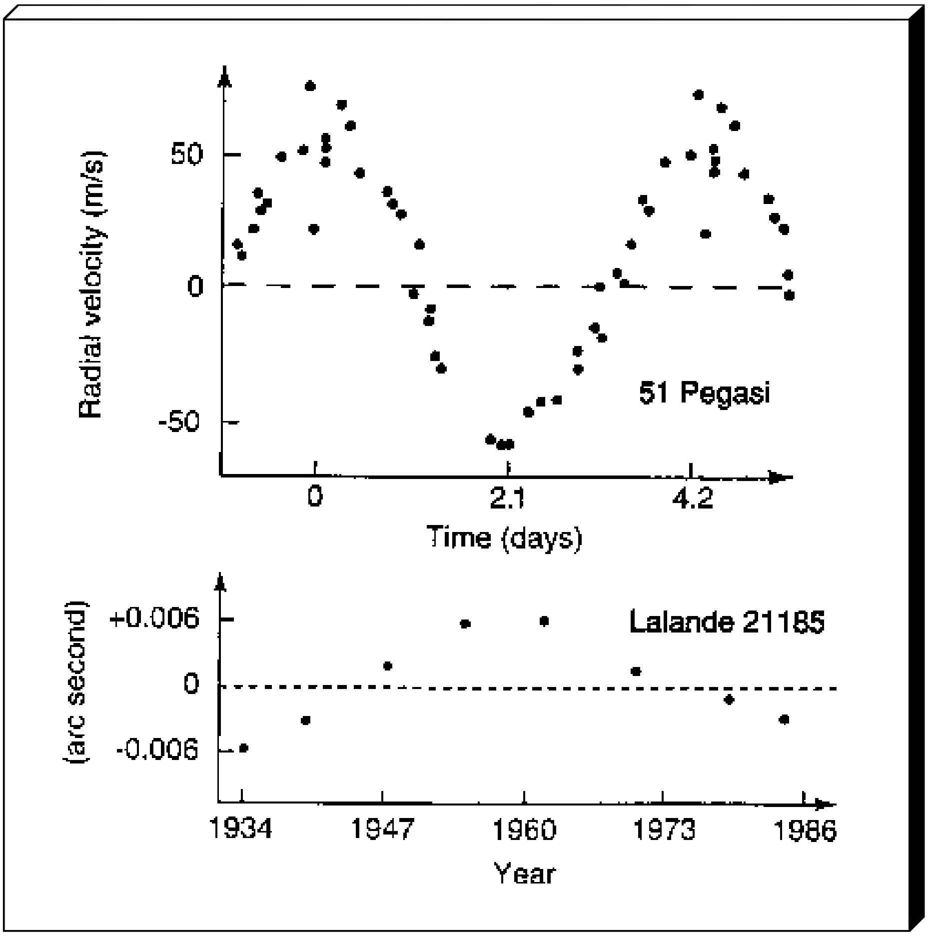

Fig. 5 – The oscillations in the line of sight motion of the star 51 Pegasi reveal the presence of a planetary object in orbit about the star. The periodic variation in the position of the star Lalande 21185 likewise reveals the presence of a planet.

already begun. There is a well-founded hope that in the near future we will not only discover many planets but also planets in formation. This, of course, will provide an immense leap forward in our search for the physical conditions for extraterrestrial life.

The conclusions to be drawn from the observations to date are: (1) the discovery of extra-solar planets by studying the motion of the parent star is

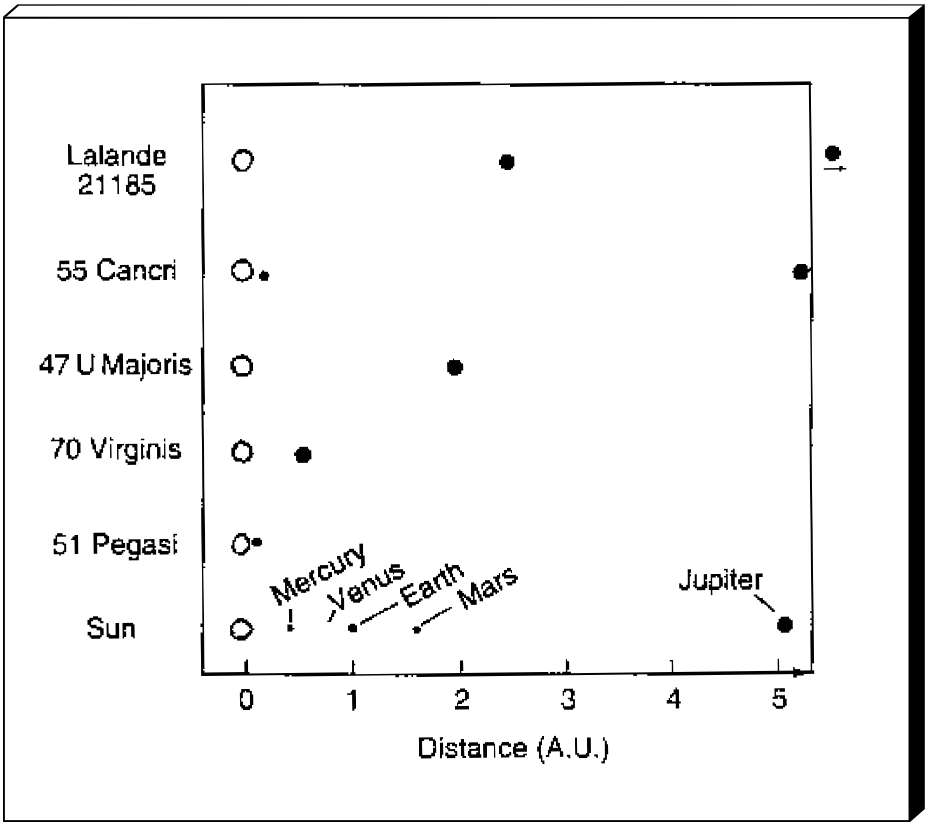

Fig. 6 – A sampling of planets (filled circles) recently discovered about nearby stars (open circles)

promising, but the results thus far are few; (2) some of the objects discovered thus far may actually be "brown dwarfs"; (3) no Earth-like planets in a habitable zone have been discovered.

Other techniques, such as high-resolution imaging in space and from the Earth, spectroscopic detection of extra-solar planetary atmospheres etc., are being developed. Ambitious programs are being developed to search by spectroscopy for biotic or pre-biotic conditions in extra-solar planets. Within the next decade we will undoubtedly discover hundreds of candidates as extra-solar planets. In 2004 the NASA will launch the Full-sky Astrometric Mapping Explorer (FAME), a space telescope designed to obtain highly precise position and brightness measurements of 40 million stars. This rich database will allow astronomers to determine with unprecedented accuracy the distance to all stars on this side of the Milky Way galaxy and to detect large planets and planetary systems around stars within 1,000 light years of the Sun. While that will be a sampling of only one percent of the distance across the Galaxy, it will increase by a factor of at least 100 the distances thus far sampled. It appears, therefore, from an observational point of view, that we will soon know whether the existence of planetary systems is a common phenomenon.

Questions for the Future

The convergence of many fields of research in modern astrophysics allows us to pose some scientific questions about the origins and evolution of the universe as a matrix from which life has evolved. We are intimately related to the energy and the matter in the universe of which we are a part. We are constantly exchanging atoms with the total reservoir of atoms in the universe. Each year 98% of the atoms in our bodies are renewed. Each time we breath we take in billions and billions of atoms recycled by the rest of breathing organisms during the past few weeks. Nothing in my genes was present a year ago. It is all new, regenerated from the available energy and matter in the universe. My skin is renewed each month and my liver each six weeks. In brief, human beings are among the most recycled beings in the universe. Life has made a relatively late appearance considering the total age of the universe (see Fig. 1) and there are three intriguing questions which it poses in terms of the evolution of the universe itself: (1) in the evolving physical universe was it inevitable that life come to be; was it by chance; can it be understood; (2) is life unique to our planet; (3) is life at the level of intelligence and self-reflection an important factor in the future evolution of the universe?

THE ROLE OF TROPICAL ATMOSPHERIC CHEMISTRY IN GLOBAL CHANGE RESEARCH: THE NEED FOR RESEARCH IN THE TROPICS AND SUBTROPICS

PAUL CRUTZEN

The main permanent components of the atmosphere N_2, O_2 and Ar together make up more than 99.9 volume % of the atmosphere. Nevertheless, the Earth's climate and the chemistry of the atmosphere are mainly determined by the remaining minor constituents, which because of their relatively low abundance are significantly affected by human activities, in particular by fossil fuel and biomass burning, chemical manufacturing, agriculture and land use changes. Most abundant among these gases is carbon dioxide, which plays essential roles as the carbon feedstock for the photosynthesis of plant matter and for the Earth's climate. CO_2, however, does not play any significant role in the chemistry of the atmosphere. Among the chemically active gases, methane (CH_4) is most abundant with a volume-mixing ratio of about 1.7 ppmv, compared to a pre-industrial value of only about 0.7 ppmv. Methane plays important roles in the photochemistry of both the troposphere and the stratosphere. The next most abundant gas of chemical importance is nitrous oxide (N_2O). Chemically almost inert in the troposphere, N_2O is removed from the atmosphere by photochemical destruction in the stratosphere. A fraction of the nitrous oxide is thereby oxidized to nitric oxide (NO), which, together with NO_2, acts as a catalyst in an ozone-destroying cycle of reactions. In the natural stratosphere, the production of ozone (O_3) by the photodissociation of O2 is largely balanced by its catalytic destruction by NO_x (= NO + NO_2). Because the abundance of N_2O is increasing by 0.2 – 0.3%/year, partially due to the increased production of N_2O in soils as a consequence of the rapidly growing application of N-fertilizer, there is an anthropogenic effect on stratospheric ozone, although at a relatively slow rate. The most important anthropogenic impact on stratospheric ozone is due to the emissions of a series of entirely manmade chlorine – (and bromine) containing compounds, in particular $CFCl_3$, CF_2Cl_2, and CCl_4. As with N_2O, these gases are only removed from the atmosphere by photodissociation in the stratosphere, thereby producing Cl and ClO radicals, which, even more efficiently than NO_x, diminish ozone, by catalytic reactions. Most surprisingly, the strongest depletions in stratospheric ozone have been found to occur over Antarctica during the springtime months of September and October. Exactly in the height region (14-21 km) where naturally, and until about 2 decades ago, a maximum in O_3 concentrations was found, O_3 has now totally vanished, resulting in major depletions in the total ozone abundance in the atmosphere and major increases in the fluxes of biologically damaging ultraviolet, so-called UV-B, radiation at the Earth surface.

The functions of ozone in the atmosphere are manifold. It acts as a filter against solar ultraviolet radiation, thereby protecting the biosphere from a large fraction of the biologically active radiation of wavelengths less than about 310 nm. About 90% of all ozone is located in the stratosphere and 10% in the troposphere. Both are substantially affected by human activities. Contrary to what has happened in the stratosphere, ozone concentrations in the troposphere have increased, as is clearly noticed during photochemical smog episodes, but also more generally in regions that are affected by anthropogenic emissions of methane and other hydrocarbon, carbon monoxide (CO) and nitric oxide (NO), such as the mid-latitude zone of the northern hemisphere and also the continental tropics and subtropics as a consequence of biomass burning during the dry season. Ozone is deleterious to the biosphere, affecting human health and plant growth, especially agricultural productivity.

The role of ozone in the troposphere is, however, not only negative. In fact, it fulfils a very important function in the removal of almost all gases that are emitted into the atmosphere by nature and human activities. The latter occurs mainly via reactions with hydroxyl (OH) radicals which are largely formed by the absorption of solar UV-B radiation by ozone, leading to the production of electronically excited O atoms which have enough energy to react with water vapour to produce hydroxyl radicals. Despite very low tropospheric concentrations, globally averaging about 4×10^{-14} by volume, it is hydroxyl, and not abundant molecular oxygen (O_2), which is responsible for cleaning the atmosphere. Because of maximum abundance of UV-B radiation and water vapour, the concentrations of hydroxyl radicals are largest in the tropics and subtropics. A quantitative understanding of the chemistry of the atmosphere requires, therefore, good knowledge of the chemistry of the tropics and subtropics.

Specifically in the tropics and subtropics there exist major gaps in knowledge and observations of many key species in tropospheric chemistry, in the first place of ozone, but also of those species which determine the oxidizing efficiency (that is OH concentrations) of the atmosphere, such as CO, hydrocarbons and NO_x. The continental tropics and subtropics are already substantially affected by mostly human-caused biomass burning. In future, agricultural and industrial activities will particularly grow in these regions on the globe. The study of the influence of these on atmospheric chemistry (e. g. ozone and hydroxyl concentrations) and climate is an important task for the atmospheric chemistry community. This requires much enhanced research activities in the tropical world which should also involve researchers from the developing world.

The present state of quantitative knowledge about particulate matter in the troposphere is even in worse shape than that of the gas phase. The role of aerosol is manifold:

1. Particulate matter can influence the chemistry of the atmosphere by providing surfaces and liquid media for chemical reactions, which often can not take place in the gas phase.

2. By the scattering and absorption of solar radiation, particulate matter plays a substantial role in the radiative properties of the atmosphere and, therefore, in the Earth's climate.

3. This influence is emphasized by the fact that atmospheric particles can serve as condensation and ice-forming nuclei. Recent studies have indicated the possibility that climate warming due to increasing levels of greenhouse gases has been substantially counteracted by the backscattering to space of solar radiation, both directly from the aerosol under cloudfree conditions or indirectly by increased albedo of clouds. Although it appears that calculated and observed temperature trends agree much better with each other when optical aerosol effects are included in global climate models, thus providing some evidence for the significance of the aerosol-climate feedback, those conclusions are still based on rather weak grounds, again largely because of lack of knowledge about the physiochemical properties and distributions of atmospheric aerosol. In particular, the above mentioned model runs were performed only considering sulfate aerosols, which are strongly derived from coal and oil burning. However, several addition-

al types of aerosol, which can likewise be influenced by human activities, are emitted into the atmosphere, such as

* smoke sunlight-absorbing aerosol, mostly from tropical and subtropical biomass burning;
* soil dust;
* organic aerosol, resulting from gaseous organic precursor emissions from vegetation;
* seasalt particles.

Clouds can provide major pathways for the chemical processing of natural and anthropogenic emissions. While this chemical cloud effect has been studied for a few major components such as SO_2, there are many more soluble and reactive atmospheric constituents whose cloud processing is largely unknown.

Neither the quantities of emissions nor the global distribution of these aerosol are even approximately known, but one thing is clear: they all play important roles in the climate and the chemistry of the atmosphere. And again, also here the main gaps in knowledge may well be in the tropics and subtropics.

The lack of knowledge also concerns the interactions of gas phase species with the aerosols. As an example, in all climate simulations the calculated distributions of sulfate aerosols have been conducted, neglecting potential interactions of anthropogenic SO_2 with the other types of aerosol. This may well mean that much of the sulfur, which is emitted into the atmosphere, may be deposited on other aerosol, such as soil dust and seasalt particles. If that is so, then no additional sulfate particle formation could take place in regions with high emissions of such particles, implying that the sulfate cooling effect may have been substantially overestimated. What is needed most now are measurements of the emissions and global distributions of the various kinds of aerosol, especially in the tropics and subtropics.

Closely connected to what has been said above about the atmospheric chemistry aspects of global change, are biosphere/atmosphere interactions, as many of the chemically and climatologically important trace gases are likewise to a substantial degree emitted into the atmosphere by the biosphere. Besides CO_2 and N_2O, we mention especially NO, CH_4, and reactive hydrocarbons which together have a substantial impact on O_3 and OH concentrations and which are increasingly impacted by human activities.

I propose, therefore, that in future “global change” research substantial attention is given to the tropics and subtropics. This also requires the involvement and training of local scientists who participate in joint field programmes: a strong scientific basis in this part of the world will in future not only benefit progress in science, but will also lead to greatly improved scientific inputs in political decision making.

WHICH ECONOMIC SYSTEM IS LIKELY TO SERVE HUMAN SOCIETIES THE BEST? THE SCIENTIFIC QUESTION

EDMOND MALINVAUD

The purpose here is to establish a framework within which scientists could bring their testimony to the Catholic Church about a highly relevant and much disputed issue. The fate of people very much depends on the institutions which shape societies, and knowledge of this dependence is a scientific question which motivates thought and research. The challenge concerns in particular what scientists can say about which economic system should be chosen.

The testimony discussed here is meant to come from economists and to be addressed to the social teaching of the Church. With this limited scope we shall, first, outline the historical development of the issue; second, describe in broad strokes the main framework within which improvement in scientific knowledge has to be achieved; and third, give some hints about answers to three sub-questions, which are taken as illustrative of what economists discuss.

I. The State of the Issue

Speaking here of the past development of objective views on our subject will simply serve to remind us of the historical background to the present question and the difficulties which were encountered in producing a scientific attitude towards it. This will be done by four selective glances: at the early history of the literature on the subject; at the hesitations which marked the twentieth century; at the present social teaching of the Church; and finally at a recent message from a few academic economists on how to manage the market economy so as to meet the development objectives of the Third World.

1. *Notes about the early history of literature on the subject*

Explaining and judging the economic system that emerged at the time of the industrial revolution was the main motivation of those intellectuals of the eighteenth and nineteenth centuries who were after a short time called economists. They were striving for objectivity, but they could not meet the standards that modern science would require. Moreover, what will be said in the next part of this paper about the conditions applying today in economics, was already the case to some extent in those times. Only in the last part of the nineteenth century did systematic use of data and rigorous formalisation begin to penetrate the discipline.

However, ideas were progressively taking the shape of theories. Those presented in the main books of, respectively, Adam Smith and Karl Marx, are good examples for anyone who wants to reflect on the positive contents of the two main strands of ideas which inspired the economists of those times.[1] As is well known, the positive assessments which were expressed did not convey the same vision. According to Smith, given the institution of free exchange the pursuit of self-interest leads to a natural order in which prices regulate economic activities and lead to efficient specialisation. According to Marx, capitalism, which had emerged at a particular historical time and provided the most suitable institutional structure of society, was subject to contradictions which would lead to its replacement by another form of social structure. But both Smith and Marx attributed a large role in their respective analyses to the theory of prices.

It was precisely in order to provide the theory of prices with stronger foundations that in the last decades of the nineteenth century a few economists engaged in what was to become a well structured research programme. This programme was pursued even beyond the middle of the twentieth century and resulted in rigorously formalised theoretical models deductively derived from sets of axioms. Such models now serve as inescapable reference points for any serious study of economic systems.

For what will follow we must note that the theory of prices, established in order to provide foundations for studies of the whole economic system, made only informal references to facts. But, mostly for other purposes in economics, a systematic use of statistical data was also needed. Starting in the first decades of the twentieth century, another important research pro-

[1] A. Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, 1776; K. Marx, *Das Kapital*, Band I, 1867, Band II, 1885, Band III, 1894.

gramme was initiated. It later developed into establishing an inductive methodology which sought to be appropriate to the conditions within which quantitative economic knowledge can be reached.

2. *Hesitations in the twentieth century*

The feasibility of the socialist planning of production and distribution was, by as early as 1900, the subject of heuristic discussions. Socialist thinkers claimed that whatever the market system could do could also be done by intelligent planning, which could even do things better, at least in terms of equity and fairness.

This basic insight became the subject of what was called 'the economic theory of socialism'. The theory used clean mathematical specifications, and in particular the theory of the general competitive equilibrium, for the representation of the market economy, in addition to another somewhat similar model which supported the instinctive perceptions of socialist thinkers. Around 1960, three broad conclusions were drawn from this theory. First, that it is precisely under the conditions which make the market system work best that socialist planning could also work well, and perhaps even better. But, second, that these conditions were not realistic – the theory had neglected a crucial difficulty in our complex economies, namely the pervasive imperfections of information, of private agents, and of governments. Third, that this difficulty was probably even more damaging for economies run by state planning than for market economies.

Ideas were also evolving in the less formalised schools or branches of economics, particularly in those trying to draw lessons from economic history. As a significant example, I may mention here the hopes entertained by many in the immediate post-World War II period, notably by a number of Christian thinkers: with less involvement of the state than was the case in the Soviet Union, economic planning was feasible in democracies. Such an approach, it was thought, could install economic systems which would be more stable, more efficient and more favourable to solidarity than the systems that had prevailed during the inter-war period. Although fewer and fewer economists shared these hopes over the subsequent decades, planning was still considered as a possible option.

In October 1963 the Pontifical Academy of Sciences held a study-week on 'The Econometric Approach to Development Planning'.[2] It had been

[2] *Pontificiae Academiae Scientiarum Scripta Varia,* N° 28, vols. I and II, 1965.

organised by the statistician and Pontifical Academician, Boldrini, and was attended by eighteen rather well-known economists, including some who were very involved in planning methods. These economists did not agree with each other fully and the debate was often tense. However, they were able to issue a common 'Final Statement' printed at the end of the proceedings (which, by the way, ran to more than 1200 pages). This statement deals with a number of points, for instance with the role of the then newly-born discipline of econometrics and with useful research directions. But it is indicative of the ideas of the time that the possible comparative advantage of the market system in ensuring efficiency in the allocation of resources is not mentioned in the 'Final Statement'. Just one paragraph comes close to questioning the ability of governments to plan economic development. Its main sentences run as follows:

> Our discussions also made clear the need for a better understanding of the capabilities as well as the limitations of various instruments of economic policies which governments can use in the pursuit of their short and long-run goals. Research on the nature of the instruments available has been neglected...This neglect has led to the adoption of goals that could not be attained by means of the available instruments and to overestimating the effectiveness of some instruments. In short, more research is needed into what governments can and cannot do in trying to foster economic development and stability.

In the two last decades of the twentieth century, prevailing ideas moved at an accelerating rate away from confidence in governments' claims to control the economy or even simply to intervene in it. Roughly speaking, the main reason was experience rather than deduction: the failure of Soviet planning became manifest; even in OECD countries people became more and more aware of costly inefficiencies in the operation of the welfare state, and more generally in public economic management; and the internationalisation and globalisation of economies made claims relating to central national direction less and less credible.

3. *The social teaching of the Church*

Although the social teaching of the Church had developed down the ages ever since the Bible, the encyclical *Rerum Novarum* (1891) of Leo XIII marked a revival in Catholic reflection on the socio-economic system. Concerned about the social problems of industrial countries, the

Pope repudiated the two ideologies of liberal capitalism and socialism. Starting from the premise that 'capital cannot do without labour, nor labour without capital', he argued for a return to a Christian environment recognising both private property and the rights of labour, which had to be realized by the social policy of the state in collaboration with trade unions. In *Quadragesimo Anno* (1931) Pius XI went further in suggesting the establishment of a new socio-economic system in which the causes of conflict between labour and capital would be strongly mitigated by the use of a corporative system. The development of Catholic social doctrine continued, thanks in particular to close collaboration, on the one hand, with Catholic social movements, and on the other with experts in the social sciences.

In 1991 the encyclical *Centesimus Annus* displayed the overall benefit to be drawn from the recent emergence of a higher degree of consensus in the academic community of economists when, concluding Chapter IV (the longest of all), the Pope wrote:

> Is [capitalism] the model which ought to be proposed to the countries of the Third World which are searching for the path to true economic and civil progress? The answer is obviously complex. If by "capitalism" is meant an economic system which recognizes the fundamental and positive role of business, the market, private property and the resulting responsibility for the means of production, as well as free human creativity in the economic sector, then the answer is certainly in the affirmative, ...But if by "capitalism" is meant a system in which freedom in the economic sector is not circumscribed within a strong juridical framework which places it at the service of human freedom in its totality, and which sees it as a particular aspect of that freedom, the core of which is ethical and religious, then the reply is certainly negative (n. 42).

This is not the place to make even an abridged summary of this rich encyclical, still less, of course, to seek to speak about the whole present social teaching of the Church on economic systems.

4. *A message from scientists about the public management of economies*

Published in 1997 by Clarendon Press, Oxford, for and on behalf of the United Nations, *Development Strategy and Management of the Market Economy* presents and explains the conclusions of a few academic economists about recommendations to be made for the countries of the Third World.[3] Here are two extracts from the short 'foreword':

> Public policy discussions should begin with the recognition of the essential role that the markets play in the efficient allocation of resources. International openness, as well as free domestic movement of goods and factors of production, are crucial. Many of the mistakes in earlier development policies arose from an inadequate appreciation of the role of markets. However, in some cases, markets either do not exist or fail to operate effectively – because of imperfect information, structural rigidities, insufficient infrastructure, or far-reaching externalities. Moreover, demands of distributive equity may end up being neglected in market allocations with unequal resource endowments. Deficiencies of these kinds can be particularly pervasive in developing and transitional economies.
>
> Instances of market failure do not imply that the use of markets should be abandoned, or that liberalization and deregulation policies are unnecessary in those economies which have tended to cramp the effective operation of markets. On the contrary they highlight the need for public policies to be informed by rigorous analysis, particularly of the nature and causes of likely market failures. Nor should we assume that governments can always eradicate market failures through intervention. Development experiences point to a wide range of government failures as well, especially when the measures aim at supplanting market signals rather than modifying them appropriately.

After having insisted on the fact that 'development is a long-term endeavour' and that the sustainability of any development process can be endangered by macroeconomic instability, the 'foreword' concludes:

> These general ideas served as the point of departure for our examination of the appropriate combination of the government and the market in the construction of development policies. There is much complementarity between these two fundamental components, and it is sensible to think of a partnership between the government and the market in the formulation and implementation of successful development strategies.

[3] E. Malinvaud, J.-C. Milleron, M. Nabli, A. Sen, A. Dasgupta, N. Stern, J. Stiglitz, K. Suzumura.

II. Conditions Surrounding Possible Improvements in Scientific Answers

In order to present explanations for the present state of the issue and to suggest how fuller scientific answers might be reached, we shall state here a few propositions about the conditions under which advances in knowledge of the question have to take place.

1. More than economics is involved, because, first, the relevant concept of 'the economic system' is broad and concerns legal, political and social institutions besides purely economic ones; because, second, what is meant by 'serving human societies' covers not only economic aims but also achievements with respect to such values as individual liberties and capabilities; and because, third, the range of feasible achievements will depend on such non-economic factors as population, the availability of natural resources, technological progress, political feasibility, the competence and devotion of governments, social cohesion, peace, and so on. Economists are of course aware of these various aspects, but they do not have full competence in dealing with them.

Such being the case, natural scientists might believe that the rational response to what turns out to be a multidisciplinary challenge ought to come from a multidisciplinary research programme. But in actual fact the implementation of such a response is highly problematic because colleagues specialising in other disciplines are seldom keen to enter a programme of that sort. They are not really interested in the purpose of the research; their knowledge is not geared to being useful for the purpose. Take for instance the question of knowing how the diffusion of the new information technologies will interact with the functioning of various economic systems: broad views about the issue are present in the press and known by economists. Would a scientist, an expert in the development of those technologies, bring relevant additional knowledge? Or take the question of knowing what could be the contribution of sociologists to the research programme, which has to come up with positive proposals rather than with radical critiques of whatever happens to exist, a programme, moreover, which stands at an intermediate level between the study of micro social structures and broad universal visions.

The opposite approach, namely for economists to appropriate the study of non-economic aspects and thereby to incorporate non-economic features into their analyses, is followed more frequently: this applies at the present time particularly to the study of political aspects, but it is not limited to the extension of this domain claimed by some economists. Such an extension is exposed to two dangers. The introduction of non-economic factors may be quite naive. If it is not, economists may rely too much on assumptions and modes of analysis which are more justified at the core of their domain than outside it. For instance, they may overestimate the real scope of cases in which self-interest is the dominant motive behind action.

Whatever the case, a tension will remain between the judgment of economists and what could come from the competence brought by other scientists, a tension which will eventually be fruitful only if it actually manages to stimulate interchange.

2. Social scientists do not strive only for objective knowledge, but also for the formation of ideologies and social norms. This is not surprising because most of those who have undertaken research and analysis into social phenomena have been motivated by concerns about some kind of social malfunctioning. They originally intended to investigate the problem and hoped to find ways of coping with it. But before seeking to engineer a remedy they have to persuade others about the existence of the problem, about the value of their proposals, about the need to join movements which will act with them. Natural scientists are also inclined to become the advocates of particular policies, but precisely because their disciplines are more 'exact', the distinction is more easily made than in social sciences where there is often an ambiguity between the two roles of scientific research and social action.

It is clear that economics increasingly tends to avoid the confusion: our discipline seems to be definitely more prone than other social sciences to the pure search for objective assessments. However, when they approach discussions about the economic system, many economists still have difficulty in separating the positive issues of scientific knowledge from normative issues. The difficulty is particularly apparent with those who have strong social motivations, or who, working in cooperation with people belonging to other social disciplines, are naturally led to adopt practices which are common to those disciplines.

3. Most academic economists shy away from approaching research closely connected with the choice of economic systems. This is a respectable position because this choice is such a complex question that the objectivity required may appear paralysing, particularly for scientists working on radically different topics within economics. The fear that they will be dragged into the realm of ideological conflict also plays a role in bringing about this approach.

But this respectable position creates a perverse self-selection of the group of academic economists who take part in debates about the economic system. Usually this group has less exacting standards of rigour. This perverse selection is not only a factor of direct disturbance but is also indirectly damaging with regard to the visibility of the 'new political economy' school, which is otherwise an entity much to be welcomed.

The school is made up of economists working at the frontier of political science on issues which involve both economic knowledge and a good understanding of how the polity functions. Most of its contributions deal with current economic policy rather than with the choice of economic systems. Unfortunately, benefiting from the scientific recognition of the school, more and more people claim in unwarranted fashion to speak under its banner, even on broad issues. This creates a new source of confusion.

4. *Economics is better at detecting dilemmas than at finding the right solutions to them.* Economists are often criticised in such terms by those who address them. Confronted with a question, especially a burning question, the typical economist patterns his or her answer according to the 'on the one hand...on the other hand' opposition. Subsequently, he or she is usually unable to offer a clear conclusion. This attitude on the whole reflects the real difficulty of the question and the limitations of economic knowledge.

Take for instance any of the major issues about the welfare-state institutions of OCDE countries (old age pensions, health care schemes, unemployment insurance...). You will find that, on the one hand, the concerns of the early promoters have been well justified: these institutions do indeed bring social benefits to the population. But, on the other hand, in their achievement of their well justified objectives, present institutions are less efficient than was expected: they are not selective enough and they are excessively exploited by people who learn how to turn the system to their own personal advantage, far beyond the original purpose of the system (basically, this follows from the fact that individuals benefit from 'asymmetries of information': some of their characteristics and some of their actions are hidden from welfare institutions). There is thus a trade-off between the extent and form of social protection and its cost in terms of the economic performance of the country. In order to decide what to do, you need accurate quantitative assessments of the true benefits and costs under alternative set-ups. But such assessments are very difficult to establish – what can be provided leaves wide margins of uncertainty, as we shall see when discussing below the question of how to select an appropriate level for the minimum wage.

At this point, in order to have a good grasp of the subject of this paper, we cannot but engage in a detour and discuss the methodology of economics.

5. *Knowledge in economics comes from original combinations of induction and deduction.* This has important consequences for what the discipline can achieve. The originality of the approach, in comparison with the natural sciences, is due to major differences in empirical sources.

Whereas economic phenomena are complex and more exposed to changes than is the case with natural phenomena, the scope for experimentation in economics is rather limited. But economics draws knowledge from two sources of evidence: it not only involves external observations of phenomena appearing at the individual or aggregate level (statistical observations), but it also draws advantage from direct, or equivalently 'internal', knowledge of a large part of the domain to be investigated. This direct knowledge involves (i) the constraints and motives ruling individual economic activities, (ii) the interactions between economic agents when they contract or act within the confines of pre-existing contracts, and (iii) the system of legal or informal institutions within which activities and interactions take place.

Separately seen, each one of these two sources of evidence is too poor to be sufficiently revealing for most of our scientific purposes. But considered jointly they bring richer information. Indeed, internal knowledge is mainly qualitative; what can be deduced from it alone is too vague. External observation bears on the results of complex phenomena, involving too many causalities to clearly exhibit the force of each cause, except within specific models which incorporate what can be derived from internal knowledge.

The professional skill of economists in relation to each subject tackled by their discipline specifically involves how best to articulate this combination between the deductive study of accepted models and the appeal to new external or perhaps internal evidence, which will make these models more informative – i.e. more specific (accepted models incorporate not only what comes from internal knowledge, but also what was already learned from the previous processing of external evidence).

In order to move ahead and suggest more concretely how economists try to tackle, and address themselves to, the main questions raised at present by the choosing of economic systems, we shall turn our attention, by way of a brief introduction, to the consideration of three cases which are taken to be illustrative: the proper concept of the market economy; the extent and challenges of globalisation; and the minimum wage as a simple example of questions which are more generally raised by the welfare state.

III. Three Substantial Topics

1. *The concept of the market economy*

Actual market economies are very complex objects and differ from one another in a number of respects. Research on them involves a large number of aspects: their market structures, with for instance the degree and form of concentration of enterprises or trade unions; the legal, regulatory and customary rules under which they function; how they develop or adapt to changes in their environment, and so forth. Research approaches and methodologies also vary from the most tightly formalised forms, with their axioms and mathematical models, to the most heuristic forms by which to comprehend new real phenomena or challenges, such as the transition to market economies of the central and eastern European countries. In order to illustrate this variety we must be selective here and focus on only two research lines: the highly formalised, which has already been introduced in Part I, and the highly heuristic, which deals with an important recent new form of contrast between two large market economies – Japan and the USA.

1. As we have seen, the discussion about socialist planning during the first half of the twentieth century referred to an ideal vision of the alternative offered by the market economy – the vision conveyed by the formalised theory of the general competitive equilibrium. The exact scope of this theory is now much more fully understood because of two strands of research. The first seeks to make the theory as rigorous and as general as possible. The second strives to study how robust the theory is by analysing deviations from its basic hypotheses in order to show why thetheory is incomplete as a representation of actual market economies, a premise to providing alternative models. In both cases the deductive approach dominates.

For our present purpose we may select two broad conclusions produced by the second strand of research. Firstly, the dynamic stability of actual economies appears questionable because rigorous attempts at formalisation of their dynamic behaviour have revealed many potential sources of instability. Since the middle of the twentieth century most research developments on the theory of the general competitive equilibrium have been concerned with time and uncertainty: the market equilibrium is meant to involve not only immediate actions – exchanges and prices – but also the plans of agents in relation to the future, the prices applying to such intertemporal exchanges as loans, expectations about future actions, and exchanges and prices in an evolving economy hit by random shocks. We understand that the research programme is wide. We are not surprised to learn that unstable evolutions are often found which may rationalise what is observed in the real world. We may hope that theory will help us to achieve a greater control of actual economic disturbances.

Secondly, market participants do not all act on the basis of the same information, and the consequences of the actual asymmetries of information are pervasive. In particular, they explain why contracts cannot deal in advance with all contingencies – contracts involving the future are incomplete. This applies to the relationship between a supplier and a client, between an employer and an employee, and so on.

These two broad conclusions are interrelated, in particular in explaining the reasons for, and the consequences of, price and wage rigidities. The second strand of research, at a more general level, brings to the fore the importance of the legal and judiciary system which governs the implementation of contracts. It also provides arguments in favour of the existence of some market regulations, some public provision of collective services, and some deliberate public economic policies.

2. Our present knowledge of the market economy is not based only on the reflections conveyed by the discussion of formalised theory expressed in mathematical models. It also derives – and probably to a great extent – from lessons empirically learned from experience. We have already pointed to the determinant role of this second source of knowledge (at the end of section I.2). Following along the same line with an illustrative example, we shall now dwell upon some of the reasons which lay behind a phenomenon which led to a complete reversal of opinions, in less than a decade, regarding the relative performances of the Japanese and the US economies.[4]

Ten years ago, surveying the US economy, which was at that time dogged by slow productivity growth, corporate downsizing and record budget deficits, many American observers looked with envy to Japanese growth levels and were inclined to think that they were related to the centralised coordination of productive activity (complementing market incentives) in a context where large corporations were run by command and control, with

[4] We draw from a speech of Professor L. Summers, now Secretary of the US department of the Treasury, at the American Academy of Arts and Sciences, 14 April 1999. See the Academy *Bulletin*, November-December 1999, vol LIII, N° 2.

relationship-driven debt finance rather than recourse to equity issues on the capital market, and an informal rather than formal enforcement of contracts. After the high US growth rates of the last decade and the stagnation of the Japanese economy, which is now embroiled in a deepening financial crisis, the same observers have reached the conclusion that the US model was better equipped to take advantage of the overall change induced by new technologies and globalisation than its Japanese counterpart.

Three reasons are put forward in order to explain why the US economy was better prepared. Firstly, when creativity and innovation are the greatest potential sources of wealth, economies need systems in which access to finance and support depends less on where you are from and more on where you are heading: the openness of the American financial system in such a case is a definite advantage. Secondly, when economic values often change quickly, in particular because technology is in a constant state of flux, the economic system ought to be flexible enough to permit companies to go quickly through painful re-engineering and restructuring, developments which have to reflect competitive realities. Thirdly, in a globalised world family links have limited reach, whereas formal contracts and the American preference for rules over understandings and for law over custom permit large-scale opportunities to be seized very quickly.

Ex post rationalisation, which can be perceived in these arguments, is no guarantee for accuracy in the prediction of future developments. However, the few characterisations which have been made refer to different features in most modern market economies, features which may well be strategic in explanations of what these economies can achieve.

Having now in mind both formal theory and the heuristic type of approach to which has just been referred to, we may still ask ourselves whether economists give sufficient attention to an important dimension of the neo-liberalist discourse. This last preaches democracy as well as free markets. It sees the two aspects as being complementary and it is obviously successful in inspiring some of the modern choices about the socio-economic system. Intuition suggests that whether and how such a complementarity between markets and democracy ought to hold is an important issue, particularly for the social teaching of the Church.

2. *The extent and the challenges of globalisation*

The importance of the international exchange of goods and ideas is by no means new. However, after the contraction imposed by the Great Depression and the Second World War, this importance has increased so much during recent decades that people often entertain the vision of a single world, within which economic activities would freely develop under a single and uniform set of rules with no distinction according to location. Reality is, of course, still rather different, particularly with regard to the employment of labour. But reference to a global economy which corresponds to this vision is relevant in discussions about the future economic system.

The principle of the unity of mankind makes the vision attractive. But when we realise that, for a long time to come, political globalisation will not be achieved, the matter becomes less clear. Interacting connections between the global economic system and a diversity of national political systems ought then to be defined. Even if we limit attention to the case of a global market economic system, the interacting connections with political systems constitute a complex issue because of the importance, in the market economy, of the legal and judicial system, of market regulations, and of economic policies, and this for the reasons suggested in the foregoing section. Given the difficulty of the general issue posed in this way, it is not surprising to learn that research about globalisation in economics deals with much narrower issues, among which the following, which we will now consider in turn.

1. Do national economies benefit from insertion into the world economy? Insertion into the world economy imposes constraints, against which public opinion often rebels, both in less developed and in advanced countries. But insertion also opens up opportunities for countries which have comparative advantages to extend their activities. The conclusions now reached by most economists who have studied the issue is based largely on observation of what has happened throughout the world over the last five decades.

Overall, the benefits offered by new opportunities have been found to far outweigh the costs imposed by market constraints: countries which have opted for an import-substitution strategy, favouring the stimulation and protection of national productions, have performed systematically less well than those which have opted for free trade and export promotion. However, the explanation for the tremendous disparities between national performances and national developments in terms of standards of living require greater scrutiny. It has been found that the main responsibilities for such disparities are of a national character: most differences in growth records reflect differences in the quality of government and in the soundness of the strategic policy choices which have been made, including those concerning international trade. But trends in the global demand and supply of commodities have also played a part, in interaction with trade policies. Moreover, we cannot expect the benefits and costs of globalisation to be evenly distributed between countries and within countries. In other words, a simple answer to the question raised can hardly suffice.

2. Has the globalisation of financial markets now gone too far? We do not find in economics at present a clear answer to this question, which some economists even tend to see as being purely academic (was it possible to resist the trends towards an increasing international mobility of capital and towards the establishment of a less distorted balance of powers between managers and shareholders in large companies?) Two concerns seem to be widely shared at present. In the first place, increases in the geographical distance between labour and capital within large international corporations are socially unhealthy. In the second, the notorious instability of financial markets might become more dangerous with globalisation. In both cases these concerns call for serious examination, and possibly the discussion of remedies. Convincing scientific responses to the challenge posed by the first concern would have to draw upon all parts of the methodology of economics and to look extensively beyond the confines of economics.

There is an obvious connection between a research programme on the instability of globalised financial markets and the programme to which we referred earlier – namely on the more general stability of equilibria in market economies. However, financial markets are special because they involve only minimal transaction costs, which have, moreover, sharply decreased during the last two decades. This implies, in particular, an increased participation of agents – called 'arbitrators' or 'speculators' – who, in trying to take advantage of small price disequilibria, help to make the markets more efficient, although they may also make these markets less stable. It thus appears that a special research programme is required in order to improve upon the overly heuristic answers now given to questions raised by the second concern mentioned above.

3. *The minimum wage*

1. Fifty years ago Western European countries chose a mixed economic system in which on the one hand freedom of contracts prevailed, with markets ruling exchanges and the formation of prices. But on the other hand, a public welfare state was established which aimed at the regulation of the macro-economy and at a redistribution of incomes to the benefit of those who are temporarily or permanently in need. The experience of recent

decades has showed that such a mixed system has worked less well than was expected. It has proved to be more costly than envisaged because in particular it has involved greater expenditure than was justified by the objectives of social policies. It has been less effective in redistributing incomes. Hints were given about the reasons for such deficiencies in section II.4.

Thus the future of welfare-state institutions poses challenging problems. Such being the case, it is natural to invite specialists to provide objective assessments of the costs and benefits of alternative welfare-state arrangements. The assessments in question would give measures of the trade-offs between costs and benefits, or between degrees of satisfaction of various objectives. Unfortunately, what is objectively known is uncomfortably vague because of large inaccuracies in the establishment of relevant economic and social parameters. The econometric difficulties which explain why this is so appear in the particular case of the minimum wage, here taken as a significant example.

2. Clearly, the existence of minimum wages in many countries derives from the perception of a need to prevent cases in which the weakest employees are exploited by their employers. Once this is accepted, the question of the appropriate level of the minimum wage immediately follows. A excessively high level will prevent the employment of the less productive workers, those who are judged by potential employers to have a lower productivity than the cost to be borne of their labour (the wage plus whatever taxes the employer has to pay because of this employment). We must also take account of the fact that the unemployed suffer not only from a lack of labour income but also from a feeling of exclusion and personal failure. A minimum wage level which is so high that it has a significant impact on employment is thus likely to have a more important social cost than the social benefit produced by the prevention of exploitation.

In order to help in the determination of the appropriate level, economists ought, therefore, to estimate the trade-off between increases in the minimum wage and increases in unemployment, which become more and more important as the minimum level is raised. A brief explanation of the main difficulties of the assessment may be the best way by which to convey a sense of the real importance of the problem.

Firstly, econometric measurement encounters difficulty most often in its attempts to allocate observed results to the various causes that play a part and combine their effects. This is an unfortunate fact which arises from the scientific conditions in which econometrics has to operate (see section II.5). Although different kinds of data sets can be, and have been, used, in all cases the identification of effects to attribute to the level of the minimum wage turns out to be problematic.

Secondly, some economists attribute to minimum wages an important indirect role in generating overall unemployment: the protection of workers is said to contribute to making all workers less willing to accept 'the verdict of the market'. Where minimum wages are generous, it is affirmed, workers more generally obtain excessively high wages, which, so the argument goes, generate unemployment. But the force of such an indirect effect is not invariant. It very much depends on: (i) the way in which the whole wage scale is determined; and (ii) whether an overall increase in wages reduces or does not reduce employment. An accurate characterisation of this indirect effect has to distinguish between quite a few different cases.

Thirdly, the trade-off between the level of the minimum wage and employment of the unskilled has an important time dimension which may be neglected and ought not to be. If the minimum wage is lowered, the impact on the income of the workers concerned will be instantaneous, whereas the increase in the chances for unemployed unskilled people to find jobs will be slow – it will appear progressively over a period covering a decade or more. But where levels of the minimum wages are high, changes in these levels should eventually have quite significant effects on the employment of the category of persons affected by these changes.

Notwithstanding these various causes of inaccuracy, knowledge progressively improves and accumulates. In particular, we know that the appropriate level of the minimum wage for a group of workers varies with the productivity of those workers. This is a particularly important consideration when one comes to the geographical dimension of regulations. In some countries or other large areas labour productivity varies a great deal from one region to another. The application of the same uniform minimum wage in all regions is likely to foster persistent unemployment in the less productive regions. We have recurrent evidence, coming from external observation, which points to this conclusion.

SUSTAINABILITY: PROSPECTS FOR A NEW MILLENNIUM

PETER H. RAVEN

Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being. However, integration of environment and development concerns and greater attention to them will lead to the fulfillment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can – in a global partnership for sustainable development. (Agenda 21, Earth Summit; Sitarz, 1993).

The noted scientists and technologists who gathered for the Congress of Arts and Sciences in St. Louis in 1904 would not have understood the meaning of those ringing words. Instead of worrying about global inequities or the destruction of the environment, they were delighted with the prospects for a world in which the possibilities for progress seemed virtually unlimited. More than a century after the introduction of the steam engine, the fruits of the Industrial Revolution had become evident on every front, and the United States was looking forward to a future of international leadership. Taking my cue from the St. Louis Congress, I shall focus many of the following remarks on the role of the United States, but shall eventually broaden that view to encompass the world, a world in which the influence of the United States and other industrialized nations is pervasive.

When the delegates assembled in 1904, they would have been mindful of the death of Queen Victoria, who had given her name to an era that had witnessed the most extraordinary scientific, technical, and industrial advances that the world had known to that point. The St. Louis World's Fair itself was celebrating not only the growing outreach and power of the United States, but also the broad vision of a diverse world that seemed to hold so much promise for the future. Theodore Roosevelt, the youngest American president, was in the White House, later to win the Nobel Peace Prize for his role in bringing about the end of the Russo-Japanese War; about to become the first American President to travel outside of the country, when he visited the construction site for the Panama Canal (completed in 1914); and poised, in defiance of Congress, to send the American Navy around the world as a show of national strength (1908).

At the same time as Americans were so excited about the prospects for the development of the airplane, of the automobile, of new modes of communication, and all of the other inventions that promised so much for the future, a few of them had also begun to realize that the world was not as unbounded and limitless as it once had seemed. Explorers had reached the far comers of the Earth, and knowledge was pouring in about its lands and its peoples: we increasingly knew what was there. Fredrick Jackson Turner, later to become America's preeminent historian, had announced the closing of the frontier, an idea that was to have great influence on collective visions of the world in the early years of the century. What were the turn-of-the-century antecedents of ecology, of sustainability, and of biodiversity – concepts that are now intellectual landmarks on the topography of the twenty-first century, but virtually unknown a hundred years ago?

The World Then and Now

At the turn of the century, after more than a hundred years of the Industrial Revolution, the global population stood at approximately 1.65 billion, with about 74 million people in the United States. In about four months, an event to be officially "celebrated" on October 12, 1999, there will 6 billion of us, including a billion added within the past 12 years, and the billion before that in 13 years. There are at present just over 270 million people in the United States. Human expectations have risen continuously over the course of the century, while the global population has more than tripled; consequently, the level of consumption in the industrialized world has risen to heights undreamed of just a few decades ago. Changes in the biosphere also have been unprecedented, with a major proportion of them having occurred during the past 50 years (Turner, 1990). Over this period, and for the past few hundred years, technologies have been invented and deployed, and the world has in what is geologically an instant of time been converted from a wild one to one in which human beings, one of an estimated 10 million species of organisms, are consuming, wasting, or diverting an estimated 45 percent of the total net biological productivity on land and using more than half of the available fresh water, locally at rates that clearly cannot be sustained for long. The properties of the atmosphere have been and are being substantially changed by human activities, almost all major fisheries are under severe pressure, and habitats throughout the world have been decimated, with populations of alien plants and animals exploding and causing enormous damage throughout the world, while species extinctions have reached levels unprecedented for tens of millions of years. Despite the optimistic tone set by the Earth Summit declaration quoted above, with perhaps 3 billion additional people joining our numbers over the next half century, we will clearly have an increasingly difficult time in maintaining our current levels of affluence or in achieving the lofty goals which our historical progress seems to have made available to us. The scales and kinds of changes in the Earth's life support systems are so differenent from what they have ever been before that we cannot base our predictions of the future, much less chart our future courses of action, on the basis of what has happened in the past (Vitousek *et al.*, 1997).

As Bill McKibben has outlined in his book "The End of Nature" (1989), we have arrived at a time when human beings are effectively managing the whole planet, for better or worse. The end of nature as he understands it is the end of nature functioning independently of human beings. This is the vision that was explicitly explored in the outstanding collection of essays, "Uncommon Ground" (Cronon, 1995). Specifically, in the field of conservation, those organisms that survive will do so because human beings manage the Earth's resources in such a way that this is possible; those that are lost will be lost for the same reason. The pressures we exert on global ecosystems are so extensive that their future is up to us. For these reasons, it has become clear that we clearly are living in the most difficult and challenging times that humanity has experienced. How did we get to this point, and what have been some of the warning signs along the way?

A mere 10,000 years ago, when crop agriculture was first developed at several widely scattered centers both in the Old World and the New, several million human beings, far fewer than the number of people who visit the museums of the Smithsonian Institution annually, populated the world, at about the density of Aboriginal peoples in Australia before European contact. The availability of larger quantities of food, on a more dependable basis that had existed before that time, created conditions for the rapid growth of the human population to an estimated 300 million at the time of Christ, a number that held more or less steady for a thousand years, grew to 1 billion around 1800, reached 2.5 billion by 1950 and will, as I mentioned above, reach 6 billion in the present year, 1999. As human numbers have grown, their impact on the environment increased also, regional evidences of overgrazing or deforestation having been regarded with dismay by some people ever since Classical times. It has been during the period of the Industrial Revolution, from the mid-eighteenth century onward, however, that the evidence of widespread human domination of the natural environment has grown so rapidly and become so obvious as to affect the world view of every person concerned with the future.

The Growth of Environmental Consciousness: Before 1900

Following Columbus' landfall in the New World five centuries ago, at a time when the global population was less than a tenth of what it is now (about 500 million), waves of people from the Old World colonized the newfound lands and grew to great numbers and great power. The same *phenomenon occurred* throughout the world, as colonial expansion and the extension of often unsustainable forms of land use rapidly changed the face of the continents (Grove, 1995). As Andrews (1999, p. 18), put it, "Colonization... was among other things an environmental policy". The ways in which relatively unspoiled lands were rapidly changed by the practices associated with colonization, and the ideal visions of such lands that persisted in the minds of Europeans far longer than they did on the ground, had a great deal to do with our collective understanding of the limited nature of local and ultimately global resources (McCormick, 1989). By the 1850s the problem of tropical deforestation was already being viewed as a problem on a global scale, and one that urgently demanded correction. Although less emphasized in the latter decades of the nineteenth century and the first half of the current one, the powerful metaphor of the destruction of Eden proved an enduring and influential one.

In Colonial America, the collective vision was one of an endless cornucopia of forests and meadows, rich in natural resources to be exploited – the destruction of the wilderness and the taming of nature were widely-accepted as desirable goals. The image of nature in all of its wonder and abundance, and the deep and abiding love of the land that Americans generally share, however, also. have their roots in this early history: the land seems inexhaustible, rich, and nurturing beyond our wildest dreams. As

Wallace Stegner (1980) put it, "While we were demonstrating ourselves the most efficient and ruthless environnient-busters in history, and slashing and burning and cuffing our way through a wilderness continent, the wilderness was working on us. It remains in us as surely as Indian names remain on the land. If the abstract dream of human liberty and human dignity became, in America, something more than an abstract dream, mark it down at least partially to the fact that we were in subtle ways subdued by what we conquered". In these words, Stegner has captured the essence of the ethical, moral, and religious overtones to environmentalism, which are fundamentally important to our perceptions of the field, and underlie our hope of progress in the future. Although much of what we say and do is materialistic and operational, the reasons that we do it lie within ourselves.

Even in colonial times, some began to take seriously the evidence of threats to the bounty of the land, and to view the profligate use of natural resources as a problem (Nash, 1982; Shabecoff, 1993; Andrews, 1999). However, it was not until the advent of industrialization, roughly from the 1830s onward in America, that massive changes in the landscape began to become evident on many different fronts. In a relatively few decades, from the mid-nineteenth century onward, most of the prairies were cleared, the remaining great forests were cut, and farms and, increasingly, cities were established everywhere in the land – the activities noted so poetically by Stegner were carried on apace. In addition, it has gradually become clear that "nature" is a profoundly human construction: it can never be separated fully from our own values and assumptions (Cronon, 1995, p. 25).

Increasingly alarmed by these trends and their perceived effects on the future productivity of the land, influential writers and public figures, mostly living in the cities of the East, began to call for the preservation of some of our national wildlands, especially in the West: the sense of passing of the wilderness ultimately had a powerful effect on the national imagination. Ralph Waldo Emerson and Henry David Thoreau re-defined our relationship with nature, laying the foundation for modem environmentalism and the concept of sustainability. At the same time, Charles Darwin, by placing the human race clearly in the biological context of its evolutionary history, helped substantially to break down the dichotomy that had been so generally accepted earlier between people and nature. Subsequently, George Perkins Marsh, America's first true environmentalist, understood well the concept of the balance of nature and brought it to the attention of a wide public, basing his appreciation on his knowledge of his native state of Vermont, as well as on his wide travels in the Mediterranean basin and elsewhere; his 1864 book, *Man and Nature; or, Physical Geography as Modified by Human Action* is a classic both of environmentalism and of ecology. Marsh saw clearly that the destruction of nature could not be sustained, and pointed out the need for care in the management of our resources for the sake of future generations. America's first national park, Yellowstone, was established the same year that Marsh's book was published. Another notable and far-sighted early experiment in re-defining the relationship between man and nature was the establishment of the Adirondack Forest Preserve, later the Adirondack Park, by New York State, in 1885.

At the same time that concern about nature, and especially about the fate of the Western lands, was growing, another important trend was greatly influencing the development of environmentalism. The explosive growth of cities and the increasing urbanization of the population brought widespread urban pollution, along with the development of a new way of life that differed remarkably from that of the countryside: the same trend that had accompanied the advances of the Industrial Revolution earlier in England and elsewhere in Europe. The new urban-centered life, and the development of the many remarkable institutions that it made possibe, provided an abundance that led to a growing equality and equity, but also gave rise to many new problems concerning the conditions under which people actually lived in those growing cities, swollen by the ranks of immigrants seeking a new life in America. Thus nearly 13 million immigrants came to the United States between 1890 and 1910, the great majority of them living in cities, where they were joined by large numbers of people moving from the farms. Coal dust, smoke, and toxic chemicals, open sewers, uncertain and often polluted water supplies, crowded and unsanitary toilets – these were the commonplace experience of urban dwellers at the turn of the century. The collective realization of what the awful crowding in cities, the squalid living conditions and urban pollution meant to the lives of people became, along with the protection of natural resources, a second element of fundamental importance in the formation of American environmentalism (Andrews, 1999, chapter 7), one that ultimately contributed enormously to the strength of the modem environmental movement (Gottlieb, 1993).

The Science of Ecology

The essays that were presented by Oscar Drude and Benjamin Robinson in St. Louis in 1904 revealed an ecology that was in its earliest stages of development. Their papers were mainly concerned with plant distribution and the organization of plant communities around the world, with no reference to any of the dynamic concepts that have come to be associated with the modem synthetic science of ecology a century later. The term "ecology" had first been proposed by the German biologist Ernest Haeckel in 1866, but Haeckel had no particularly novel insights about the field. In developing the concept, he was referring to the web that linked organisms with their environment, an idea directly related to the notion of "natural history" as it had been understood earlier. Essentially, the science of ecology is one that has developed entirely in the twentieth century.

At first, it was the study of plant ecology, and the relationships within plant communities that dominated ecology; but oceanography, linmology, and other disciplinary approaches now part of the field were developed during the same years. Efforts to chart the limits of plant distribution and to understand those limits in a historical sense were pursued actively, with terrestrial animal ecology coming along later (McIntosh, 1985). F.E. Clements, who had served as secretary for the ecology section of the 1904 St. Louis meeting, became an important pioneer and leader in the development of more dynamic concepts, and helped to lead ecology away from its roots as a purely descriptive discipline. During the same years, H.C. Cowles, at the University of Chicago, played a seminal role in the development of the science by adding his valuable insights to the concept of plant succession. Eventually, the British ecologist C. Elton in his book "Animal Ecology" (1927) laid the foundations for terrestrial animal ecology. There followed rapidly in the ensuing decades the development of quantitative community ecology as a field, and an appreciation of the dynamics of populations and of the relationships between populations in communities, the flow of energy and the movement of materials in communities (in the second half of the century), and finally the emergence of a science of systems ecology, in the development of which the American ecologists Eugene P. and Howard T. Odum played major roles.

Like all branches of science, ecology has become increasingly quantitative and theoretical, with an emphasis on mathematical modeling, population ecology, and feedback loops; scientists such as G. Evelyn Hutchinson and his student Robert MacArthur were important contributors in this area.

It needs to be emphasized at this point that ecology and environmentalism are by no means synonymous concepts: ecology is in fact a scientific discipline that deals with the relationships between organisms and with their environment and develops logical ways examining and making predictions concerning them. A concept such as “sustainable development” is necessarily based on the principles of ecology, as those principles operate in a social and economic context. Notwithstanding this fundamental distinction, the development of the field of ecology into a strong scientific discipline during the course of the twentieth century is one of the factors of fundamental importance allowing us to evaluate the dilemma that faces us as we enter the new millennium. The whole set of biological relationships that it comprises provide the basis for understanding the reactions of different sets of populations, whether of humans or of other kinds of organisms, to their changing environment. Ecology likewise, especially through the synthetic field of conservation biology, illuminates the fundamental principles on which our biological heritage can potentially be conserved for our future welfare.

Environmentalism in Twentieth-Century America

Environmentalism in the United Stateswas marked in the early years of the twentieth century by the emergence of the remarkable leadership of Gifford Pinchot, John Muir, and Theodore Roosevelt. These inspirational men considered in their individual ways that our natural resources should be managed so as to serve the needs of the future as well as those of the present: their influence was enormous, and persists to the present. They built particularly on the concept of parks and reserves, and that of safeguarding natural resources for all people. Among the events that marked the growth of environmentalism prior to World War II were the establishment of the National Audubon Society (1905), the controversy over Hetch Hetchy Valley in the Sierra Nevada of California (the valley was granted to San Francisco in 1913), the Migratory Bird Treaty Act established with Canada (1918), the establishment of the Civilian Conservation Corps (1933), and the passage of much Federal legislation to regulate forests, water, and soil erosion during the 1930s. The influence of cartoonist Ding Darling (1876-1962; Lendt, 1979), who published widely syndicated and much-appreciated environmental cartoons from 1916 onward, cannot be overestimated. As chief of the Biological Survey (later the Fish and Wildlife Service) in the 1930s, and because of his wide networking, he contributed a great deal to making Americans aware of their environment and what they were doing to it, and to the world – he clearly has an international vision of the environment, and projected that vision in many ways. And these are just a few samples of what was going on during those years.

During World War II, environmental concerns were largely sidetracked by the urgent ones associated with the war effort. Following the war, there occurred a period characterized by what Shabecoff (1993) called “careless optimism and materialism.”. Environmental concern gradually returned, however, as people were confronted on all sides with widespread evidence of severe problems. During these years, events such as the severe air pollution that occurred in Donora, Pennsylvania, in 1948, in which 20 people died and 14,000 became ill; the London “Killer Smog” that left 4,000 people dead in 1952; and concern over soil loss, water pollution, and the destruction of natural resources drew widespread attention and lead to the enactment of new laws protecting people and natural lands.

One of the first books to call attention to these problems forcefully to a general audience was Fairfield Osborn’s “Our Plundered Planet” (1948), which by its title as well as by its substance helped to stimulate serious and widespread debate. Osborn considered “the grand and ultimate illusion [to be] that man could provide a substitute for the elemental workings of nature”. The concerns expressed by Osborn gradually moved to center stage in the public mind, his book having played a major role in stimulating concern about the environment and the directions in which we were heading.

Aldo Leopold, a great conservationist and philosopher, wrote some of the most stirring essays in the history of the field; his posthumously-published “A Sand County Almanac” (1949) has inspired generations of environmentalists. This book immediately became a landmark of the movement towards what we would now call sustainability, and is surely one of America’s finest gifts to the world conservation movement, and thus to future generations. Leopold’s “land ethic” speaks of a complex world dominated by human beings, who thus have either the power of good, nurturing care of their land, or the ability to degrade and destroy it. In his words, it “changes the role of *Homo sapiens* from conqueror of the land-community to plain member and citizen of it” (1943, p. 216).

Partly as a result of the writings of leaders such as Osborn and Leopold, and partly because of the increasing evidence of environmental degradation seen ever more widely, public concern over environmental matters reached new heights in the 1960s. The publication of “This is the American Earth,” an exhibit-format book featuring the photographs of Ansel Adams and the poems of Nancy Newhall, by the Sierra Club in 1960, made a significant contribution to environmentalism and a new way of thinking about the Earth at a spiritual level at the start of the decade. Over the following years, many influential writers and speakers began to warn of the dangers of excessive human domination of the Earth, generalizing from when had earlier been seen as individual, unconnected problems. They did so during a half century in which a world population that had grown by 850 million people during the preceding 50 years to a record level of 2.5 billion continued to increase at accelerated rates to its present level of 6 billion people. Such growth, coupled with industrial expansion from 1945 onward and increasing expectations on the part of consumers, greatly increased the strains on all ecological systems in ways that had become widely evident by the 1950s and 1960s.

In 1962, the first excepts of Rachael Carson's "Silent Spring" appeared in The New Yorker, and our common vision of our relationships with our planet were permanently altered. Clearly the most important environmental book written in America, "Silent Spring" focuses on chemical pesticides, but with clear vision charts the destruction that technology can bring if carelessly applied. Carson presents a vision of a future world in which intelligent people can create a sustainable world. By doing so in such a convincing way, she moved environmentalism permanently to the center of the American agenda. Another landmark work was published near the end of the decade, when Paul Ehrlich's best-seller "The Population Bomb" (1968) dramatized and made available for a wide public for the first time the problems associated with rapid growth in human population, in effect adding a new dimension to the environmental debates.

The gathering momentum of the environmental movement culminated on Earth Day, April 22, 1970, when some 20 million Americans, one of every ten people in the nation, massed to demonstrate their concern over the state of the environment. Environmentalism had emerged as a mass social movement, resonating with civil rights and the other major social movements of the day. Many new environmental groups had been organized, and they were growing rapidly along with others that had been in existence earlier. Starting with the National Environmental Policy Act, signed into law on January 1, 1970, the concerns of those who were attempting to lay the foundations for a sustainable future were embodied in our laws, followed by the passage of the Clean Air Act. The Environmental Protection Agency was created at the end of the same year; the Clean Water Act in 1972. Of particular significance was the establishment of the Endangered Species Act in 1973: the world's most comprehensive legislation dealing with the conservation of biological diversity.

Earth Day in 1990 was even more significant in demonstrating the degree to which environmentalism had pervaded every aspect of American society, from corporations to consumer life styles, and become a force that could not again be disregarded in the formation of public policy. What it called into focus, however, was that even though the environmentalism that was so strongly expressed in the 1960s had resulted in the establishment of outstanding environmental legislation, these accomplishments were not enough. Human nature combined with a failure to appreciate the global environmental situation, based partly on wishful thinking – the desire to continue on with "business as usual" – has resulted in bizarre and distorted conclusions like those of Easterbrook (1995), or the ones found daily in much of the economic press. Taken at face value, the assertions presented in such works would lead one to believe either that world economics functions in a vacuum, or that the natural productivity of the Earth and its maintenance and healthy functioning is of no interest in calculating human futures. Evidently, relatively few people in positions of authority are willing to deal with the shock that comes when the global scale of these problems is recognized. Yet it is patently true that economic growth can be sustained over the long run only in the context of care for the environment.

Global Environmentalism

On a world scale, the formation of the United Nations in 1946 and the subsequent development of the organization gradually led to an increasing emphasis on problems associated with the environment. In 1968, the International Conference of Experts for Rational Use and Conservation of the Biosphere met in Paris under the auspices of UNESCO, and became the first major international meeting to examine human impacts on the environment. From this conference came the Man in the Biosphere (MAB) program, which specifically called for new ways of considering this relationship, and implementing improvements in it.

Four years later, in response to environmental problems in the Baltic region, the 1972 United Nations Conference on the Human Environment was convened in Stockholm. Here, the Canadian Maurice Strong began his brilliant international environmental career, and, when acting as the head of the secretariat, brought about a strong examination of the relationship between the environment and development that has dominated international considerations of this area ever since. Building in part on the concepts expressed by the microbiologist and conservationist Rene Dubos, the conference examined the conditions under which human beings could exist in harmony with the rest of nature. Dubos' famous admonition, "think globally, act locally," has greatly influenced environmentalists, and his role in developing the concepts examined at Stockholm was of seminal importance., At the conference itself, a memorable role was played by Indian Prime Minister Indira Gandhi, who stated, “The inherent conflict is not between conservation and development but between environment and the reckless exploitation of man and the earth in the name of efficiency”.

Among the products of the Stockholm conference was the formation of the Governing Council for Environmental Programs, a body that changed the following year (1973) into the United Nations Environment Program (UNEP), with its headquarters in Nairobi, Kenya. Its global orientation has served the world well during the 26 years of its existence, with many solid accomplishments to its credit. Nonetheless, its status as an agency supported by voluntary contributions has tended to marginalize some of its themes and the conclusions of its deliberations, and many believe that a more central role for the environment within the U.N. General Assembly would be an appropriate response to the world environmental situation as we prepare to enter the new millennium. The scope of the world’s problems does indeed seem to cry out for such a solution.

Another, and very different, event of key significance in the elaboration of the concept of sustainability was the publication by the Club of Rome of “The Limits to Growth” (Meadows *et al.*, 1972). The study this book reports uses comprehensive mathematical models to develop its conclusion that if present trends in world population continued, that the limits to growth on the planet would be reached within a hundred years; that the underlying conditions could be changed to establish a condition of ecological and economic stability that would last for the indefinite future; but that if the world’s people decided to change these conditions, that the sooner they began, the more effective their actions would be. The remarkable feature of this book was its presentation of a comprehensive global model in which the various environmental, social, and economic factors that affect the human future could be considered in context for the first time. Although the study was widely reviled, particularly in economic circles, for the details of its projections, the majesty of its vision is as impressive today as when it first appeared, and the kind of reasoning it made possible remains fundamentally important. No enduring vision of the world’s future can fail to take into account the effects of population growth, of affluence (consumption per person), or of the use of inappropriate technology, all of which need to be addressed in achieving global sustainability.

In practice, however, the appearance of the book set off a strong debate between the “cornucopians,” who believed that environmental threats are grossly exaggerated, and that we should continue on with business as usual, and those who hold that catastrophes of various kinds are either upon us or just around the comer. What is certain in this debate is that early and intelligent actions will be required if some of the directions we are pursuing are to be changed; and change them we certainly must.

In the preceding remarks, I have deliberately not emphasized the growth of the global environmental movement, which parallels in different ways and with various regional and national characteristics that of the American environmental movement. McCormick (1989) and others have done a good job of charting the growth of what has become the largest social movement in history. One need only consider words such as Chernobyl, Times Beach, Brent Spar, and the Rainbow Warrior to understand how the concepts of global environmentalism have pervaded our collective consciousness, and why. Certainly this movement, from the grassroots up through organizations, will have a major role to play in the organization of our responses to the problems that we so evidently confront as we enter the new millennium.

Sustainability

In the history of the environmental movement, "sustainability" is a recent concept that has proved powerful in describing the different factors that bear on our future. In 1987, the World Commission on Environment and Development published "Our Common Future," a report on the global environment in a human context. This report, which was adopted by the U.N. General Assembly calls for sustainable development as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". In other words, it combines the need to protect natural resources with the improvement of living standards: ecological systems and human systems working in harmony with one another. Pointing out that the problems of the environment in relation to human development are well known, the Commission called for urgent action to address these problems and to set the world on a sound course for the future. The Commission produced a brilliant and well-reasoned report, with strong recommendations in most fields affected by sustainable development. To some extent, its conclusions were built into the Declaration from the Rio de Janeiro meeting five years later, but the objectives it laid out so clearly are still to be fully met. Achieving economic growth while taking into sufficient account environmental and social realities is our common goal, but it is very difficult to achieve. Despite the strong emphasis given this area in the recommendations of the Earth Summit at Rio (Sitarz, 1993), relatively little progress has been made. Why has this been the case?

Twenty years after the Stockholm conference, it had become obvious that the state of the environment had deteriorated greatly from its 1972 condition. The authors of “Limits to Growth” (Meadows *et al.*, 1992, p. 2) wrote in their new analysis, “Beyond the Limits,” “Human society has overshot its limits, for the same reasons that other overshoots occur. Changes are too fast. Signals are late, incomplete, distorted, ignored or denied. Momentum is great. Responses are slow... if a correction is not made, a collapse of some sort is not only possible but certain, and it could occur within the lifetimes of many who are alive today”.

In that same year, 1992, and once again organized under the tireless and effective leadership of Maurice Strong, the 1992 World Conference on Environment and Development in Rio de Janeiro re-emphasized and expanded upon these themes, and led to the development of several important international treaties, including ones dealing with climate change and a second with the protection, sustainable use, and fair and equitable sharing of biological diversity. The Earth Summit was a success to some degree, with the vision articulated twenty years earlier at Stockholm now widely accepted, and the depth of the problems confronting humanity generally understood. In addition, the enhanced role of non-governmental organizations (NGOs) in the meeting was an important advance that suggests one of the fundamental ways in which change may occur in the future. In addition, the organization of the Business Council for Sustainable Development was another important theme of the meeting, and one that has grown subsequently. The replenishment of the Global Environment Facility (GEF; formed in 1991), a financial mechanism to help developing countries deal with global warming, biodiversity loss, the pollution of international waters, and depletion of the ozone layer, was one important step, and several groups established or given new mandates at the time of the Rio meeting are addressing problems of great importance. What the Earth Summit did bring into sharp focus, however, was the huge difference between the concerns of the governments of industrialized countries, a fifth of the world’s population with a per capita income of more than $20,000 and a life expectancy of 75 years, with those of the developing countries, four-fifths of the world’s people, with a per capita income of about $1,200 and a life expectancy of 63 years. Some 1.3 billion people live in acute poverty, with incomes of less than $1 per day, 840 million of them receiving less than 80 percent of the U.N.-recommended minimum caloric intake, and thus literally starving.

When it became definite that India would attain independence, a British journalist interviewing Gandhi asked whether India would now follow the British pattern of development. Gandhi replied “It took Britain half the resources of the planet to achieve this prosperity. How many planets will a country like India require?” More recently, Wackernagel and Rees (1995) and others have emphasized again that if everyone lived at the standard of industrialized countries, it would take two additional planets comparable to Earth to support them, three more if the population should double; and that if worldwide standards of living should double over the next 40 years, twelve additional “Earths”. Aspirations to such a standard of living are clearly unattainable, and yet advertising continually tells everyone that it is both appropriate and achievable. Even those who already live in rich countries continually strive to seek to improve their standards of living. The paradox presented by these relationships can be solved only by achieving a stable population, finding a sustainable level of consumption globally, accepting social justice as the norm for global development, and developing improved technologies and practices to make sustainable development possible.

We certainly understand better than ever the nature of the problems confronting us, but our willingness to deal with them, as we enter the new millennium, remains very limited, whether they be global warming, the destruction of forests, toxic pollution, the control of nuclear arms, or the destruction of the biological diversity on which we so confidently hope to base so much of our future prosperity. Seven years after the Earth Summit, industrialized nations have not funded the important recommendations of Agenda 21, the principal document that emerged from the meeting, and seem less interested in taking those recommendations seriously as time goes by. The lack of leadership by the United States, the world’s wealthiest nation, has meant that the aspirations and plans developed in Rio de Janeiro in 1992 have mostly not been realized. How then can *we* and those who come after us expect to enjoy the benefits of a peaceful, healthy, and prosperous world in the twenty-first century and beyond?

Our collective inability, or perhaps unwillingness, to deal with conditions in the poorer parts of the world, on the one had, and the consumption patterns and lifestyles in more affluent parts of the world, on the other, pose serious obstacles to the attainment of global sustainability. With four-fifths of the world’s people sharing the benefits of only 15 percent of the world’s economy and their countries home to less than a tenth of its scientists and engineers, it is clear that the global system will operate properly only if there are increasedfinancial contributions from the North. In most of the South, environments are deteriorating rapidly, and for large areas, the conditions in which people live are clearly unacceptable and unstable, often leading directly to. environmental degradation (Shabecoff, 1996). Perhaps, as Shabecoff outlined, *we* are on the verge of a new enlightenment about the environment, but there are *few* indications that this is in fact the case.

Even though future societies based on information seem to promise less environmental degradation, the world view that so many of us share seems an unsuitable one for building a sustainable world. As Kai Lee (1993, p. 200) puts it, "How much misery will it take to make a global norm of sustainability first visible, then credible, then feasible, then inevitable? We do not know. And we do not know if the lessons of environmental disaster can be learned in time to ward off still more suffering. However bleak that prospect, we in the rich nations must bear the certain knowledge that our societies are both historically responsible for many of the circumstances that imprison the poor and that we will on average fare much better than they. Against this background it is possible to see that sustainable development is not a goal, not a condition likely to be attained on earth, as we know it. Rather, it is more like freedom or justice, a direction in which we must strive, along which we search for a life good enough to warrant our comforts".

Biodiversity

The word "biodiversity," which was coined by Walter G. Rosen at the U.S. National Research Council in 1986, in connection with the organization of a National Forum on "BioDiversity" sponsored by the U.S. National Academy of Sciences and the Smithsonian Institution (Wilson, 1988). Although it was a contraction of the familiar phrase "biological diversity," the new term took an expanded meaning, and as Takacs (1996) points out, has become the rallying cry currently used by biologists and others to draw attention to the global ecological crisis broadly. At the 1986 conference, we were still largely dealing with a concept of "biological diversity" that tended to connote the army of species in the world, our knowledge of theta, and the degree to which they were threatened by extinction. In contrast, "biodiversity," includes not only the genetic variation of those species but also all of the ways in which they interact with one another in communities and ecosystems – the entire fabric of life on Earth. Viewed in this broader way, biodiversity becomes the stuff of sustainable development, our primary hope for sustainable management of the planet in the future, and, of course, the resource on which we hope to base the coming "age of biology" over the decades to come. In other words, a concept that started as "biological diversity," transformed into "biodiversity," has added to its original connotation of a set of individual organisms a much broader social meaning. In that sense, it approaches the meaning of earlier broad concepts such as "wildlife" or "nature".

It is notable that the formation of the Society of Conservation Biology occurred in – the same year (1986) as the original conference on biodiversity. Like the conference itself, the formation of the Society signaled the maturity of an interdisciplinary effort in which the strands had been coming together for a number of years. An increasing maturity, based to some extent on the concepts that had been presented so poetically and well by Aldo Leopold 40 years earlier (Takacs, 1996), had deepened and broadened the conservation movement and the ways in which we can aspire to nurture the land and its living creatures.

The immediate inspiration for the formation of the concept of biodiversity was the sense of loss presented so clearly by authors such as Paul and Anne Ehrlich and Norman Myers in the 1970s and 1980s. Arguments based on the economic value of individual species, which are unquestionable and need not be elaborated here; those based on the value of ecosystem services, which in turn depend on interactions between species; and fundamental moral and ethical values all play important roles in explaining the reasons for the loss of biodiversity, estimated to amount to two-thirds of the species on Earth by the end of the coming century (Pimm and Brooks, 1999). Without biodiversity, we cannot respond well to the challenges we face, including global climate change: how will we form the new productive and stable biological systems of the, future? A habitable planet requires the maintenance of the living systems that support all living things on Earth, including human beings.

Current extinction rates are several hundred times higher than those that have prevailed for tens of millions of years, and habitat destruction continues apace, so that extinction rates of 1,000 to 10,000 times those that existed in the past will wipe out species at a rate that has not prevailed since the end of the Cretaceous Period, some 65 million years ago – at just the time when humanity bases so much of its future hopes on its ability to use those species for human benefit. Furthermore, we have charted only a small fraction of the Earth's biodiversity, perhaps 1.6 million eukaryotic species even given a name of an estimated total number of perhaps 10 million, with next to nothing on a global scale really known about such critically important groups as bacteria, fungi, and many groups of marine organisms. What we are losing, we do not even know: and perhaps never will.

A View of the Future

Over the course of the twentieth century, it has become overwhelmingly apparent that humanity cannot expect a healthy, peaceful, and productive future – in other words, a sustainable one – if we continue to live off the Earth's capital, rather than its interest: natural productivity. A world in which people are using or wasting nearly half of the total terrestrial photosynthetic productivity, one in which more than half of the available fresh water is already appropriated for human use, one in which the characteristics of the atmosphere are being altered rapidly, and one in which the species on which we hope to base the construction of sustainable and productive systems at the level of individual species and that of communities are disappearing in huge numbers – such a world will not be able to continue with its profligacy much longer without severe crashes of major ecological and economic systems (Meadows *et al.*, 1992). Global security likewise depends ultimately on environmental sustainability rather than on the expenditure of a huge proportion of the world's economic output to fund armies for rich, industrialized nations and poor ones alike (Myers, 1995). Food security, health, social justice – all are dependent on rising above our parochial and perhaps ingrained views of how to live, and learning together how to manage our planetary home for our common benefit. Empowering women throughout the world, seeking means to raise their status, and alleviating their poverty – microcredit has proved an effective strategy in this important effort – constitute among the most important actions to be taken to achieve sustainable development Science and technology need to be fully applied in our striving toward global sustainability (Lee, 1993), but they alone will clearly not be enough. The new Social Contract for Science called for so forcefully by Lubchenco (1998), one in which scientists will address the most urgent needs of society; communicate their knowledge and understanding widely in order to inform society's decisions; and exercise good judgment, wisdom, and humility, constitutes a powerful call to action in a world that needs such action badly.

As the century comes to its end, it seems clear that the regulation of economic policy, with allowances for supporting the actions of the private sector, will have more impact on the environment than direct legislative initiatives. Conservative economists and radical environmentalists agree that the true value of the materials that we are using must become the basis of the sustainable commerce of the future, and that irrational taxes that drive unsustainable activities by mis-stating the value of their materials should be abandoned. Indeed, Myers and Kent (1998) have estimated that perverse subsidies leading to the destruction of natural resources worldwide amount to some $1.5 trillion annually, approximately twice as large as total global military spending, and larger than the economies of all nations on Earth except the five largest – recognizing the undesirable nature of these subsidies and eliminating them or changing them in ways that will contribute to the. sustainability of global ecosystems and resources would be one of the most important actions that humanity could take as we enter the new millennium. Perhaps the world's major corporations could in their own interest pursue an agenda in which the actual prices of resources were taken into account. In the many design and construction community, for example, architects and building scientists are just now starting to operate by the rules of such an agenda, conserving energy and using new life cycle analysis (LCA) software tools to evaluate the environmental costs, such as resource depletion, greenhous gas emissions, and energy consumption, of materials from "cradle to grave". Green consumerism is growing rapidly, with more than 31 million certified acres supplying "green" wood products in 1999. In addition, and of great importance, national and global systems of green accounting to reflect the full environmental costs of economic activities would help.

By pursuing strategies of the sort just reviewed, it might actually be possible to improve the potential condition of the world, and to counteract humanity's partly hard-wired tendency to behave as if we were still highly dispersed hunter-gatherers, rather than members of a rapidly growing human race comprising six billion people, some very rich, but many living in abject poverty. How could we build the political will to accomplish this? In view of the failure of the United States and other leading industrialized countries to address responsibly the agenda proposed at the Earth Summit in Rio de Janeiro in 1992, we cannot legitimately enter the new millennium with a sense of optimism. Despite this, we must be as effective as we can for the sake of those who will follow us, and we have significant choices to make that will clearly influence the shape of the world in the future, as analyzed effectively by Allen Hammond (1998).

Concretely, we could continue to strive to move sustainability closer to the center of the United Nations agenda, where it would be recognized as the most powerful factor in determining human futures. The United States could ratify the Convention on Biological Diversity, and all parties could refocus its activities on its three key objectives, which will help to conserve biodiversity and improve livelihoods, rather than allowing it to be consumed by questions of gene technology that have at best a marginal bearing on the survival of species around the world. The reform of the activities of the Convention, and their redirection towards appropriate objectives, would be a major step forward in the field of sustainable development. A global plan for the preservation of species, properly funded, would result in the greatest gift that, we could possibly give to our descendants.

On the other hand, it may be that the model of a world driven by nations and the kinds of international institutions that were established in the wake of World War 11 will not prove to be dominant in the future. On the one hand, there is growing evidence that enlightened corporations are increasingly realizing that understanding and working with the conditions of sustainable development is a necessary prerequisite for success in the corporate world of the future (Hawken, 1993). John Browne, CEO of BP, for example, has set the company on a course that will embrace alternative energy sources and energy conservation, reasoning that in the face of global warming, they must do this if they are to continue to be a profitable energy company in the future. How much more likely BP is to prosper than companies that ignore the conclusions about climate change that are so evident to the scientific community? Ray Anderson, chairman of Interface, an Atlanta-based carpet manufacturer, is likewise reorganizing his company's efforts around the conditions of the future, where sustainability will be a necessary condition of successful business, rather than those of the past. There are signs that the forestry and fisheries industries are starting to take sustainability seriously, and indications that consumers will increasingly demand appropriate certification for such products because of their concern for the environment. If corporations listen carefully to their stakeholders and take care to operate sustainably, they will affect the actions of governments and international agencies significantly and help to create conditions for their own prosperity, and for the world's sustainability. Frameworks such as that developed by The Natural Step, a Swedish organization that is having much influence throughout the industrialized world, will provide convenient blueprints to help guide us along the path of sustainability – but Kau Lee's

(1993) principle that sustainability can perhaps best be viewed as an ideal, like justice, should be kept carefully in mind as we travel in that direction.

The kinds of grassroots activities that are promoting sustainability on a local basis have become a powerful force throughout the world: perhaps they are fundamentally only a reemphasis of what has been traditional. Whether establishing local clinics and sustainable industries in the Biligiri Rangan Hills of south India, people-based ecotourism centers in native lands in Kenya, rebuilding a broken landscape at the Bookmark Biosphere Reserve in South Australia, learning how to ranch sustainable on the vast grasslands of the Malpai Borderlands of New Mexico and Arizona, or simply rooting out alien plants on Albany Hill in the San Francisco Bay Area, the people who are pursuing sustainability in a direct and personal way will hugely affect the shape of the world in the future. Outstanding books like those by Baskin (1997) and Daily (1997), explaining in detail how nature works and how we benefit from it in ways that most of us never consider will continue to play an important role in stimulating our desire to achieve sustainability. For example, watershed protection, the determination of local climates, and the protection of crops by birds and beneficial insects, including pollinators, that live in the ecosystems surrounding them are examples of ecosystem services – goods that nature provides without charge if we maintain sufficiently the integrity of the ecosystems that support them. In the light of this awareness, growing numbers of people will find ways to consume less energy, to recycle their materials, to participate in the political process, to promote the acceptance of international understanding as a prerequisite for sustainability, and to support others, individually or in organized groups, who are pursuing these objectives.

For the basic conditions of change must clearly come from within us. A small minority of Earth's residents cannot continue to consume such a large majority of Earth's potentially sustainable productivity. By doing so, they will untimely destabilize their own future, as well as the futures of all other people. Population, overconsumption (among others, Schor, 1998, offers a powerful analysis of overconsumption in America), and the use of appropriate technology must all be brought into the equation if our common objective is to achieve a sustainable world in the new millennium. As Paul Hawken (1993) has put it so well, we need completely new ways of thinking about our place on Earth and the ways in which we relate to the functioning of natural systems if we are to find a better way to live in harmony with nature. Nothing less than a new industrial revolution (Hawken, Lovins, and Lovins, 1999) and a new agriculture (Conway, 1997) are required to make possible the sustainable world of the future. The task is incredibly challenging, but it is nonetheless one that we much undertake if we responsibly understand the realities of our situation, and for the enduring good of those who come after us. It is also a fundamentally spiritual task. As Cronon (1955, p. 90) put it, “If wildness can stop being (just) out there and start being (also) in here, if it can start being as human as it is natural, then perhaps we can get on with the unending task of struggling to live rightly in the world – not just in, the garden, not just in the wilderness, but in the home that encompasses them both”.

In the words of Gandhi, most appropriate as we chart our course for the new millennium, “The world provides enough to satisfy everyman’s need, but not everyman’s greed”. These words illustrated why Wilson (1993) was able to conclude that humanity would be able to overcome its drive to environmental domination and self-propagation with reason – why, in short, we are not necessarily suicidal in our approach to the world. In the spirit of Gandhi, one of the greatest leaders of our century, let us take his thoughts to heart and find the new inspiration that we so badly need at this incredibly challenging time. Global arguments may have little impact on the behaviors of individuals unless they perceive the crisis as unbearably severe, something that impinges on people’s lives in dramatic and frightening ways. By then it will be too late. Our ethics and our values must change, and they must change because we come to understand that by changing we will be happier people, guaranteeing a decent future for our children on a healthier planet in more vibrant democracy in better neighborhoods and communities.

Many of the world’s life-support systems are deteriorating rapidly and visibly, and it is clear that in the future our planet will be less diverse, less resilient, and less interesting than it is now; in the face of these trends, the most important truth is that the actual dimensions of that world will depend on what we do with our many institutions, and with the spiritual dimensions of our own dedication. Clearly, the opportunities that are available to us now are very much greater than those contemplated with such joy by those who gathered in St. Louis in 1904, and the stakes are much higher.

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CHOICE, RESPONSIBILITY, AND PROBLEMS OF POPULATION

BERNARDO COLOMBO

1. Looking into the Past

The further we strain our eyes into the remote past, the more uncertain becomes our assessment of the size of the world's population, whatever the efforts we make and the instruments we use in carrying out such an inquiry. It has been stated that the estimates made for the beginning of the Christian era might be wrong by a factor of two. The figures advanced by archaeologists and those quoted in the Bible from the census of King David are even more divergent. And the extreme conjectures made as to the number inhabitants of North America before 1492 are in a ratio of 1 to 12, and of 1 to 15 for the whole continent. In spite of such uncertainties, it can be plausibly stated that from the birth of Christ until the beginning of the eighteenth century the annual population growth may have been on average well below one per thousand. This means more than a thousand years were needed for the population to double. And if we go even further back in our attempt to quantify population dynamics in the past, to when subsistence slowly began to be achieved by agriculture instead of by simple hunting and gathering, we can assume that there was a much lower rate of population growth.

Overall in this picture we can recognise the domination of the force of mortality. The impact of mortality was twofold. There was the elimination of survivors and the strong limitations placed on the years spent by women during their reproductive age. Equally, there was the factor of prolonged breast-feeding which reduced the duration of the time periods open to conception. In order to resist such conditions, and in order to maintain the population at practically stationary levels, mankind was compelled for a long time to take full advantage of its reproductive potential. The maximum recorded level of fertility is that experienced by the Hutterites during the period 1921-1930, with an average of 10.9 children before menopause for a woman who married at twenty, and three less if she postponed marriage by five years. This result underlines the importance of marriage habits. What happened before the modern era coexisted with local and general oscillations in the size of populations. The study of certain regions clearly demonstrates the effects of mortality crises. To combat such crises recourse was made to changing marriage patterns and practices. This permitted the recovery of population levels and of related economic standards. Within marriage, unhindered procreation was the normal rule. As a result, a responsible choice about marriage could act as an efficient safety valve in the case of populations where marriage was not universal and took place rather late in life.

2. The Demographic Revolution

In modern times a turning point in population increase in what have since become the developed countries took place in the eighteenth century. This led slowly but steadily to a new equilibrium between births and deaths. The impact was to be observed first in the control of sickness and mortality, and then in the sphere of fertility. It is not particularly important to try here to clarify what was the most relevant factor in shaping the development of the death rate: the epidemiological component (after the ravages of plague in the seventeenth century this pestilence ceased to wreak havoc); the increase in the availability of food (potatoes and maize may be mentioned); or the innovations introduced by Jenner, and so forth. The result is what really matters to us, and more specifically a major increase in life expectancy and the fact that almost all women are reaching the age of fifty.

With regard to the decline in birth rate – the other phenomenon responsible for this demographic transition – it is to be observed that the research into this area has attributed this development to a series of historical factors: industrialisation, urbanisation, secularisation, schooling, and a number of others. However, each explanation which is cited comes up against exceptions which weaken its general explanatory value. Industrialisation first took place in a country – Great Britain – where the decrease in fertility started late in the day. The same happened in Germany, where, furthermore, for a long time there had been a strong tradition of compulsory schooling. And the first signs of a containment of births appeared in rural zones of France. Lastly, with regard to secularisation, what connection does it really have with the baby boom anyway? Whatever the causes, in this area, too, it is the results which really matter.

Having made these points, it is easy to understand why it is so difficult to transfer these very debatable interpretations of previous trends in developed countries to what has taken place recently in the rest of the world. This difficulty is compounded by the fact that what happens in the more disadvantaged regions depends largely on their exposure to external influences: the control of mortality is an example of this. Here again, let us pay attention to the results: these underline the very fast transition which is underway in the developing world and show an extreme accentuation of the consequences of a temporary imbalance between the components of growth. In the recent past in Kenya the rates of growth were around 4% per annum, which correspond to a doubling of the population in less than eighteen years. This happened due to a situation in which, while death rates declined much faster than had ever previously been the case, early and generalised marriage, together with high levels of marital fertility, continued to prevail at previous levels. A computation carried out by Ansley Coale – a U.S. demographer – twenty-five years ago helps to clarify what that means. Ansley calculated that, at a rate of increase of 2% per annum (the rate which obtained at that time), in 6,000 years the mass of the world population would reach the volume of a sphere expanding at the speed of light. It should be emphasised that the exceptional level cited for Kenya is inferior to that which, given present controls of sickness and mortality, and with full realisation of its reproductive potential, mankind could possibly obtain.

All this shows that, given the state of our present knowledge, only one conclusion is really possible: the new conditions of the domination of mortality in the long run require the need for a globally inescapable drastic containment of potential fertility – on average a little more than two births per woman. In other words, mankind has built a wall in front of it which blocks its path, and which at present appears insurmountable.

It should be underlined, at this point, that what happened in the developed regions with regard to the dynamics of fertility did not take place under any pressure from above. It occurred as a consequence of free and autonomous decisions, taken at the micro-level of families acting in a certain social, economic, cultural context. The same cannot be said for some countries which are in a state of development: the strenuous campaigns for sterilisation in the history of one specific country, and the persisting policy of the one-child family in another, are prominent examples of this. The same may be said of certain strong pressures applied by the outside world, and even by international organisations. It is clear that this impinges on fundamental human rights. And here we encounter the core of the problems of today and of tomorrow.

3. Choice and Responsibility

3.1 At the Micro-level

'All couples and individuals have the basic right to decide freely and responsibly the number and spacing of their children and to have the information, education and means to do so; the responsibility of couples and individuals in the exercise of this right takes into account the needs of their living and future children, and their responsibility towards the community'. So dictates the World Population Plan of Action approved in Bucharest in 1974. A richer text, in terms of the concerns of this contribution, was inserted in 1968 into the Pastoral Instruction 'Gaudium et Spes' issued by Vatican Council II. In this, among the values quoted for the guidance of sound personal decisions, spouses were invited to take into account their reciprocal personal good – something which emphasised the shared responsibility of the couple. The principle of freedom of choice for parents as opposed to external interference is thus certainly established. But at the same time it is stated that this fundamental right is linked to responsible choice, and not just to any kind of choice. Responsibility and freedom of choice are complex concepts which need to be examined in detail. I cannot be responsible unless I find myself in a context of freedom which even if limited allows me a real multiplicity of attainable alternatives. Responsible action implies reference to a value and to alternative options; to the knowledge of these latter and of the consequences of the choices which are thus taken; to the availability of suitable means by which to achieve the goal wished for, or which duty demands; to the ability to evaluate and grade alternatives, and to make rational decisions about them. Responsible choice, it is clear, requires personal education.

3.2 At the Level of Governance

But whose duty and task is it to ensure everybody can have desired and wanted children? Children, indeed, whom one might consciously decide not to have because of circumstances behind one's own control brought about by social injustice or other people's mistakes and misdeeds. The exercise of responsibility cannot be seen one-sidedly. Otherwise, the right to procreate responsibly, which is strictly linked to that of free marriage, would be practically ignored for those who live in poverty through no fault of their own. Here we encounter the function of government. In fact, a government has a duty, and therefore a right, to engage in initiatives to the best of its cognitive and organisational abilities, for the sake of the higher aims which guide its life.

But it is difficult to speak of interventions in matters relating to demographic policy which do not run the risk of causing more harm than they intend to cure if they are not supported by adequate social policies. Research into the best paths to be followed to ensure a reduction in fertility, while maintaining a variability between families which reflects the free choices taken by the persons concerned, remains incomplete. We have before us a current and shocking demonstration of the eternal problem of the search for a system of social organisation which conserves the ever fragile equilibrium between authority and the consensus of citizens. At the level of individuals, the achievement of a satisfactory solution seems to require the attainment of personal autonomy in conformity with the heteronomy of a social order which permits the maximum perfection of every individual's own being. Without this personal tension, no organisational solution suitable to man, which is carried through by the state, can stand on its own two feet. The same holds true if the present situation of several developed countries is considered. Here the level of fertility is so low that replacement is not achieved. In Italy various sample surveys taken in recent years by an organ of the National Research Council have consistently recorded an ideal number of two children per woman. For several years only two thirds of that level has been reached. In my opinion, this can be seen as an expression of a sort of social illness, which will eventually worsen the problems produced by a rapidly ageing population. Faced with this situation, we seem to need some kind of revolution which carries out a complete restructuring of society as a whole.

3.3 At the Level of Society

Individuals and families on one side, and government or any public authority on the other, are responsible for choices. But they do not operate in a vacuum – they take decisions within the context of society as a whole and its cultural background. To make this point clear, I would like to give an example. In certain populations there is a strong preference – whatever the reason may be for such a state of affairs – for the birth of a son rather than a daughter. Abnormally high ratios of males over females at birth are thereby consistently registered. Selective abortion is the main cause, and this is not something which is imposed by an authority. Similar results – and this is another example – were observed for two years in the sixties in a technologically advanced country. The reason, this time, was the belief that girls born in those years were liable to produce problems. As a consequence of such behaviour, a portion of males arriving at marriageable age were denied monogamous marriage.

In my opinion, something of the same kind can be seen in certain sad facts which are now before our eyes. Population movements, whether free or forced, have always been important in shaping the territorial distribution of the population. Among these are to be found interventions which have the character of 'ethnic cleansing', a policy which sometimes ends in genocide. Such actions may be guided and imposed from above, by people raising them as a flag to bolster their own prestige. But it would be difficult for them to become a mass phenomenon if they were not supported by the cultural background of society as a whole. In such choices there is, I am afraid, a shared responsibility on the part of governors and governed. The most striking development, in recent times, in the area of population movements, is the phenomenon of urbanisation, particularly in developing countries. Political leaders can partly be responsible for this development. The political power of urban concentrations is much higher than that of a dispersed rural population. Because of this fact, it is possible that such leaders provide differential advantages to people living in cities. The usual push and pull forces then become stronger and lead to the unfavourable displacement of people and economic development.

Those in political power and the man in the street come together in the adoption of a position of relative inertia in facing up to the problems of population. Slowly but inexorably these problems will manifest their strong impact on demographic structures and dynamics, and with a number of related consequences. But at a specific moment it is difficult to understand the relevance of these issues to today's isolated actions which become easily postponed.

4. Looking into the Future

In this paper attention has not been paid to the well-known extreme variety of demographic situations which are now to be found in different countries. In the same way I have not dwelt upon the enormous changes which have taken place in the composition and distribution of the population of the world and which will lead to the already mentioned differentials in the growth of the various regions. The purpose has been, rather, to illuminate a long-term horizon which involves the whole of mankind. We have seen that, while we have reached an unprecedented personal freedom of choice in birth regulation, at the same time we are about to experience severe and inescapable constraints.

The achievement of a stationary population level has its costs. There is the risk that reasons for tension could become institutionalised in the case of small families. Interpersonal relations could be impoverished, the dangers of generational conflicts increased, and psychological problems overcome only with difficulty. In general, the educational potentiality of the family could deteriorate. To this can be added the social marginalisation which could be suffered by the much wider band of ageing people. Life would be greyer. In this approaching reality, I see exacting problems emerging which involve the whole of humanity, which, to solve them, will not be able to place trust in science and technology alone. To come to terms with these new realities, man will have to draw upon all his most deeply hidden spiritual energies.

THE SEARCH FOR MAN

JULIÁN MARÍAS

I will be short, because we have little time. I am going to talk about the search for man. I think there is a now a tendency, maybe even a temptation, on the one hand to prefer primitivism to full forms of reality, and on the other to embrace what might be called the myth of time, the idea of a simple duration which explains everything irrespective of what actually happens during that time. There is also a tendency to reduce realities to their constituent elements.

Many people say that man is extremely old. We frequently hear or read about the hundreds of thousands of years of the existence of man. The general idea is that man is extremely old, but for 98% of this time it seems that nothing happened. There was no change. This 'mankind' was beneath the level of what we understand by man. I think the point is to give an account of ourselves, and the accepted idea is that this to be found by unearthing the remains of man, that is to say bones, just bones, but I think even an animal is a living being, is a pattern of life, is a repertory of vital actions, and not mere bones.

I am afraid it is difficult to explain the fact that mankind for an enormous period of time did not change, did not display the attributes we find in ourselves, and that then in a few thousands of years there was an enormous acceleration, and that this mankind created everything we have, everything by which we define ourselves.

I think this is very unlikely. It is difficult to accept this. I think that the continuity, the biological continuity between animal and man, is evident. Of course doctors are now making transplants from organs, from animal organs, and placing them in the human body. This shows not only that the primates, but all higher animals, are very close physically, biologically, to man, but I think man is something different: a human person is a reality which is extremely different from all other realities, because in the reality of man, of the person, there is embedded unreality.

All realities are real, are present, existing, but this is not true of man. Man lives in the future, is expectation, project, insecurity, something which does not exist, and this is surprising, a reality which is extremely different from all other realities. If you look for instance at the birth of a person, it is evident that what the child is comes from his parents and our ancestors, and from the elements of the world, of the cosmic world of course, but in the whole he is entirely different, irreducible not only to his parents but also to our ancestors and to the cosmic world and even to God, to whom he may say 'no'.

This is, therefore, an entirely different reality, and I think that if you consider the whole you find something absolutely different. There is a tendency to deny or to doubt the creation of mankind. This is a very thorny question which is very difficult. I am sure it is not easy to solve, because we do not have the Creator, we do not find him, He is not present, He is not available. There is something different here. The creation of mankind is a very problematic subject which we approach with difficulty. But the creation of each man is entirely different because of this characteristic of being irreducible. The person who is born, who shares this reality which is unknown in the rest of the world, this reality with unreality, which consists in unreality, is something entirely new, something which adds to the rest of the world, including his parents. This means that we cannot find the Creator, we have to look for Him or to infer Him, but the fact of creation is evident, absolutely evident, because we understand by creation the radical innovation of reality, the appearance of a reality which is entirely new, which cannot be denied by others. This is what we call reality.

It is a very interesting linguistic fact that in Spanish a child, a small child, is called "*una creatura*", and that in Portuguese the term is "*una criança*". That is to say that the child is understood as something which is a creation, a new creation irreducible to others, to anything.

We speak of evidence and there are two types of evidence. On the one hand, there is the evidence of things, the evidence of reality. On the other hand, there is the intellectual evidence. For instance, we have a rock. A rock is evident, and the geologist knows what it is, how this rock was produced, and this evidence is what makes science and philosophy. A man is also evident, but the point is that man now prefers theories to evidence, and if there is a theory which says that this cannot be so, the man of our time rejects evidence and sticks to theory.

For instance, man is free, man lives as though he were free. We know that we are free, we have to decide, we are necessarily free. We have to take decisions and make choices. Everybody judges men because they are free, because we live as though they were free, but if there is a theory which says that man is not free, most men now reject the evidence of freedom and stick to the theory that man is not free.

This is what I call the fragility of evidence, which is something very important. I think that often people hear or read something which is evident and accept this evidence and see things this way and after a while under the pressure of what is said, of what is accepted generally, of what is repeated by the media and so on, they lose the evidence they had at first, they reject it, and they return to the point of view held prior to the discovery of this evidence. I think this is extremely important.

Therefore I think we have to give an account of ourselves, to give an account of what we are, of what man is, the man that we know that we are. Many theories speak of the 'missing link', but there is no living missing link. In reality, in the real world, there is nothing which is not either man or non-man. There is nothing which raises doubts. We cannot point to any reality about which we are not sure. There is either man or non-man. It is unlikely that there were missing links, and none of them exist now or is real in our world. Therefore I think it is better to think of reality such as it is, such as we find it, with the attributes which we consider belong to man, to human life, and this is mostly unreality, anticipation, project. Man is not a present reality, he is mostly a future reality: of the future and uncertain. There is no certainty. The word 'future' is not exact because the future means what will be, and we do not know if something will be. It can be; we project it; we imagine it. The reality of man is highly imaginary.

I think that present theories of man involve the search for something which is not man, for something which is not what we call a person.

SCIENCE FACING THE CRISIS OF SENSE

FRANCIS JACQUES

I do not know precisely what you want to hear from philosophy on the eve of the plenary session. Yet, I have been invited to join your working group from this point of view. Thank you for welcoming me, a philosopher, amongst you eminent scientists. Now, philosophy might be expected

– To provide a link between science and humanism. And then, what kind of mediation?

– To take part in the heuristic debate in a different way, with the goal of introducing some variety. Then, I might ask, what sort of variety?

– And to put crucial issues into the wider context of the crisis of significance (or 'sense').

This is the first insight in my present approach. It presupposes that *there is* a genuine loss of sense. The same point is made by other thinkers: 'The extraordinary success of the systematic investigation of the universe thanks to the procedures of the positive sciences is on a par with scepticism or indifference to sense.'[1] 'It is as if our society had renounced, even in its educational instances, to make propositions as to what regards the order of sense'.[2]

It could very well be denied by many scientists that there is *any* crisis at all within the domain of science. If there is a crisis of the meaningful, or rather a crisis of sense, this phrase does not belong to scientific terminology but rather to cultural notions. The Holy Father speaks of a 'culture of death'. We are indeed witnessing the end of what marked the European

[1] G. Cottier, 'Médiations philosophiques dans les rapports entre la science et la foi', *Science et foi* (Desclée, 1982), p. 112 (my translation).

[2] J. Doré, 'La foi chrétienne dans la société d'aujourd'hui', *Une Parole pour la vie*, (Cerf, 1998), p. 197 (my translation).

landscape throughout the nineteenth century: man was to be the end of man, he had to acquire the necessary means for this aim, even at the ultimate risk of using himself for that very means. A concomitant crisis of the educational system has affected the transmission of the finalities of our society which are increasingly denied by the young. It concerns the aims and purposes required of man by man. The heart of the crisis is reached when the very notion of crisis becomes problematic.

What changes in the topography of modern rationality could account for the breaking of coaptation between faith, reason and life? This is a typical question for philosophy. As the philosopher's mediation has been requested, I will drop some hints and make some suggestions.

Granted that truth finally releases a sense of sense, yet, today, one can hardly challenge priority being given to the question of sense. It should be explicitely raised in matters of discursive strategy. As a subordinate – though no less fundamental – issue, I will formulate the question of how to define the critical thinking which can ground the space of sense. Afterwards, in a rather provocative way, I will deal with some logical consequences of critical realism for the place of science in order to facilitate the debate.

The answer will be elaborated in three stages: the identification of the specific activity of science in the reality of questioning; recognition of the external and internal limits of scientific problematicity; and its reintegration and reorganisation in the field of sense.

I. The Question of Sense

Roughly speaking, sense in the full-fledged connotations of the word has to be delineated from meaning from a logico-linguistic point of view. When we say: a sense of life and death, the question of sense, and when we analyse the different meanings to be ascribed to the word 'sense', we come across various denotations.

Sense or a *direction* from past to future. That of the proper way of life. To give sense to the scientific venture would be to assert that science knows where it is going, and this would be a utopia. *The* direction of life is something different: it concerns man in his integrality, in every dimension of his proper world.

Sense or an *aim*. If life has meaning, it progresses towards some good. If science has *a* sense, it must have one aim, at least the increase of objective knowledge. Now, the purposes of man no longer appear to him as being able to ensure his own human nature. High-technology achievements demand such large concentrations of men and such a precise division of labour that this entails the under-development of whole parts of humankind. The avowed aim and object of the medical sciences is to fight for good health against illness. But it also happens that they also involve man in manipulations and dispose of his right to live or to die. In most cases, but not in every case, the ends prove to be in full contradiction with themselves, at the very moment at which they seem to have been achieved.

Sense also reads as *intelligibility* as far as man is concerned. Man cannot live in an absurd world. Once more, science is endowed with significance in so far it gives access to some sort of intelligibility through the modelization of reality.

Lastly, sense means *hope*. The religious sense of faith is a way to anticipate what we hope, to speak a meaningful truth, a realized sense.

Every scientist who gives a predominant place to significance in his thought 'must be confronted with the task of examining, directly or indirectly, in constantly renewed form, the process and aim of science in the light of the question of sense'. By itself, science is not on its own able to provide complete answers to this question.

As a first approximation, the space of sense can be defined as a place for an open dialogue, that is, where the scientist, the philosopher and the theologian could recover complementary functions and agree on the course of scientific investigation, the identity of man, the religious quest for salvation, and philosophical mediation.

The Interrogative Approach

Now, if there is a quest for sense or significance, a second point can be made clear. Epistemologists and logicians, such as R. Gale, J. Hintikka, and more explicitly I. Lakatos,[3] have constucted an interrogative theory of scientific research with precise determinants and constraints on questions and answers. The questions must refer to observational and experimental data within the framework of a theoretical model; the answers must fit this theoretical form which is selected according to its capacity to solve 'problems' in the strict meaning of the word.

Science denies itself the right to come to conclusions in the matter of questions which, because of their own nature, are not 'objective' because

[3] I. Lakatos, *The Methodology of Scientific Research Programs* (Cambridge, 1978).

they relate to models of living. Science debars itself from the questions of sense and value, whereas life is led actually by sense and values. It informs our material and social environments, but has no power to tell us how we should handle our mastership over them. So far so good.

Scientific questioning – including the inventing and solving of problems – is *not* the only possibility (let us designate it as 'problematicity'). It cannot be denied that there is also a philosophical questioning with its own types of questions: is there a difference between meaning and sense? Does sense exist at all? For whom does sense exist? And in addition, how should we characterize the different inquiries into sense: perhaps as informal, recurrent and radical questioning?

Theological questioning shows another structure. It does not exactly run from question to answer but from the appeal of God to the response of man. In the *Confessions* of Augustine we discover this shift from a philosophical to a theological questioning – mourning the death of a friend, he writes: *ego mihi factus eram magna quaestio*. New demands arise within new dynamics for posing questions – numbering among them not only the essence of the *ego* but also the status of time, the category of events in theological history and others...This new possibility can no longer be defined as 'problematicity' in the scientific manner nor as radical questioning in the philosophical style, but as the 'elucidation of mystery' (*mysterium fidei*). Faith should not be reducible to a system of beliefs in the private area.

Possibly we should add the literary or poetic questioning: take for instance Kafka's inquest into guilt in totaliterian countries or the search for the sense of death by R.M. Rilke. Poets, scientists, theologians and philosophers have as many different ways of asking questions about one and the same abyss, and they have as many diverse relations to the unknown.

Let us sketch along these lines a philosophically minded research program. Systematic inquiry should be carried out in relation to the following questions:

> a) What are the main features of these modes of questioning and correspondingly what are the characteristics of the types of texts that give expression to them? Asking what happens in the universe when we suppose that its radius is tending towards zero, is not to be confused with an inquiry about the metaphysical outbreak of being or the supernatural creation of the world.[4]

[4] J. Earman, *Bangs, Crunches,Whimpers and Shrieks. Singularities and Acausalities in Relativistic Spacetimes* (Oxford University Press, 1995), p. 210.

The constraints of physics cannot bind the Creator. But precisely to the extent that a supernatural cause of the beginning of the universe does not have to answer to the constraints of nature, scientists *qua* scientists do not have the right to ignore it.

b) How to define the main categories numbering as orientations for these questionings. Theological categories like Creation, Revelation, Justification, Incarnation, Redemption...are not scientific categories like beginning, causality or evolution, even if they present an apparent synonymy.

c) As far as thinking is interrogating goes, what is the transcendental status of the competential modalities of thinking? We remember the famous questions of Kant: what can I know? What should I do? What may we hope (*was dürfen wir hoffen?*). They provide three autonomous fields of transcendental inquiry, not without cross-connections which have to be defined.

About Anthropology

Let us see some of the consequences of the very conception of anthropology. Part of the question of sense depends on man's identity. What is it to be a man? We should not give too ready an answer, still less an answer on a single mode of interrogation. One should so to say let the question formulate itself in accordance with the wide-ranging operating modes of human interrogativity in a harmonous culture.

The search for man is multidimensional. Of course it is not equivalent to determining man as an object: this is the *problem* of man. Scientific anthropology describes the objective characteristics of man as seen from his objective qualities, an animal able to stand up, to make and use tools, to bury the dead of his community. The result of evolutive hominisation.

– On the other hand man may be seen as a poetical enigma, with the typical variations and oscillations of meaning you can discover in the humanities, since Greek tragediis. For instance, Goethe's statement in *Faustus: ich bin der Geist der stets verneint*...So goes the *enigma* of man.

– Furthermore, man may be seen as a *radical question* for himself, as the ultimate foundation of the cultural signs of humanisation. How is man to understand his world as an object, and how is he to understand himself as a being able to engage in multiple questioning?

Confronted with an anxiety-inducing obligation to have to define, from the evolutive theory of the world, the vision he has of himself.

– Finally, man could be seen as a *mystery* to which Revelation alone can introduce us. Man cannot keep his self at a distance. He has to face things which are altogether disproportionate to himself. For him, living is being related to God, to others, to the created universe. These relations are constitutive of his being. In so far as mystery is a source of inspiration, it is illumininating intelligence striving to understand. Thus man's nature transcends consciousness, as well as the objective knowledge he can have of it. Something of what is at stake will manifest itself: the mystery of man, the very impossibility of man defining himself, since for an essential part he shares in God's want of definition. The most impregnable and inexpugnable depth of man's identity would be alienated if deprived of its relationship with God.

In short, there would exist philosophical and theological anthropologies together with a scientific anthropology. We should dare to say so in our days and keep on reminding ourselves of this fact.[5]

We are aware that latter-day scientific anthropology was born of the parting from the philosophical questioning of man's essential being 'considered as' a universalising totalitarian myth issuing from man's reason. It even came to identify man as a natural objet. Thus, it appears that 'dissolving' man – not constructing man – is the aim of scientific research in the social sciences.'[6] Several reductionist statements seem to point to the will to have done with man, reducing the mental to the brain, the ego to a series of disincarnate events and so on. In fact, it should be possible again to formulate a number of features brought to light by humanistic studies in accordance with philosophical anthropology (such as personal status, creative power, absolute desire, jubilation due to knowledge), or in accordance with Christian anthropology (such as the status of created being, the disposition to search for salvation or an incarnated being's estate). Is this to be wished for? It all depends upon the quality of the reformulation, which can never be incompatible with a shift in categorisation.

The very first shift actually appears in Gn 3, 7. In the narration of the Fall, the Seducer sounds a warning note: the fruit of the Tree of Life will

[5] F. Jacques, 'Apologétique et théologie fondamentale après Maurice Blondel. De la controverse au dialogue', *Philosophie et apologétique* (P. Capelle ed., Cerf, 1999), pp. 287 ss.

[6] C. Levi-Strauss, *La Pensée sauvage* (Plon, 1962).

turn to poison should man lay hands on it. Incertitude shatters the primeval world of trust; nature appears cruel and inhuman. In taking hold of the religious categorial competence and usurping the knowledge God had reserved to himself (not omniscience, the ability of telling right from wrong), man denied his condition of created being. His view of things altered. The retribution for it? A distortion of desire towards lust, the exploitation of man and the universe by sheer will-power and covetous desires. Such are at least the essence of the temptation and its consequence: the withdrawing of God who would henceforth hide his Face from man's knowledge. The story of the garden of Eden does not mention that desire for knowledge and power could have been justified if it had not turned into lust. P. Tillich is the most honest of all exegetes when he writes: 'One is given but little evidence of the relation of Adam to the fruit of the Tree of Life whose access he had obtained at first and seen denied afterwards; he may not enjoy eternity without God. Likewise one can infer by analogy that he cannot possess knowledge without God, either.'[7]

The Bible's narrative from Genesis, according to Biblical anthropology, and the myth of Protagoras, according to the philosophical anthropology of Plato, attest to the existence of levels in the ontological structure of man in multiple coordinates. Both texts agree on one point: man has kept on asking about his own self from the very beginning of his existence; man to himself, so intimate and also so mysterious, is not just a product of nature nor a promethean being, nor even a political animal.

II. The 'Inter-Competential' Dialogue

As far as the practical consequences are concerned, it would be suitable, P. Germain suggested, to create a device to designate working points of agreement between us: the experts in this committee representative of 'spiritual, cultural, philosophical and religious values' (or 'thinking' as I suggested personally). The function of this suitable device being 'an open dialogue' between science in the positive and precise epistemological meaning of the word and the other modes of thinking and questioning. Division or 'schism among the minds' (Laurent Schwarz) is to be avoided. In a pluralistic society dialogue is possibly the only means of coexistence. But the purpose behind establishing an open dialogue which would preserve a cultural *equilibrium and balance* between the essential

[7] P. Tillich, *Existence and the Christ.*

prospects of the search for man, does not mean encountering no difficulties at all.

Briefly sketched: how should we conceive co-operation among the experts in the absence of any methodology towards a dynamic for such open dialogue between science, philosophy and religion? Let us notice that there is an added problem for the theology of dialogues which might be interconfessional or interreligious...I would like to argue in favour of this sort of dialogue which I would prefer to call inter-competential.

> – Now about its possibility. We have some knowledge of partial approximation of it. The consultative committees of bio-ethics usually organize debates and discussions in a rather informal way, a few other working groups do as well. Why not seize the opportunity? Even if we should not over-simplify our relation to the unknown especially in a period of crisis of meaning, and even if we should preserve internal limitations in such a critical period.
>
> – I come to the difficulties and dangers we would have to face. First, dialogue in the democratic and rigorous sense of the word tends to be confused with 'plain conversation', 'polemics', 'negotiation', 'contradictory discussion'. As yet, the notion has not been conceived as a definite heuristic way of thinking. Second, each form of questioning tries to re-categorize others in perfect good faith. Each tends to stand alone in front of the fundamentals. I do not believe any longer that one and the same man can be an expert or a good scholar in more than one speciality, but he can control and rectify the formulation other experts are forging for his own questions and answers.

Another point to be elaborated, concerning the nature of the correlations between modes of interrogation: are they of a contradictory, contrary, complementary, or even of a compatible nature? They depend upon ideas concerning the relationship beween hypothesis, observation, and theoretical modelization. Their explanations, even the bare facts, are what they are only in accordance with the kind of categorization provided by a culture and the way the latter interrogates the world. But what is most crucial is their transcendental articulation.

Man for science... He cannot stand outside his mind so as to get a view of things, man and the universe. Man is involved in questioning through research, in fundamentally categorizing again and again the various classes of facts, and as a result is involved in the building up of theories, doctrines, interpretative systems and ideologies, to go back to the epistemic distinctions of K. Popper. How is man to understand himself in his own multiple ways of thinking – that is the most fundamental question, *Die Hauptfrage*, Kant would have said.

Science and the Crisis of Sense

This question, after the questioning we have just outlined, requires a broad answer. It will not be impossible for science to face a crisis in sense if the scientists listen to experts of other modes of thinking and first of all recognize them at their face-value, and listen and work in committees like this one. The practice of thinking comes to the practice of different relations to the unknown in correlation with the main modes of questioning. At the risk of incurring a reproach of reiteration, I venture to repeat that scientific questioning speaks of our interest in positive knowledge because our survival is at stake; the questioning of poetics stems from a legitimate wish to express an enigmatic facticity, the richness and varieties of the 'humanities' using a literary langage as means of communication between persons; and the religious questioning originates from a desire to elucidate a mysterious donation; each with a different categorial orientation, each on a different level of organization.

In the eyes of mere ideology, all forms of relationship between humans appear to be reduced to a single pattern, all realities transformed into objects and all objects into pieces of apparatus. Science becomes a cause of rupture in civilization. Yet, at the synodal session which concluded on October 23th 1999, many bishops declared that the time for ideological struggle against modern culture – more particularly against those of its determinants called science and theology – is now superseded. Away with that endless pessimistic view on the relations of Christian faith to science! Enough of incommunication and the harmful hits at each other!

It should be made clear that scientific quest for truth exceeds the concern for technical applications, its epistemological autonomy prevents it from being subjugated by economic interests. Of course this fact does not render it able to respond to the question of significance. The location of science in human culture has to be re-assigned. Part of the problem depends on the very identification of reason. At this price, only, could some real work be carried out on the venture of science, and only as long as scientists are ready to admit that non-scientific questions can arise from other parts of the scenery.

Should we speak here of a scientific – that is operative, mathematico-experimental – kind of rationality? Or of a rightly orientated reason, the *recta ratio*, taken into account by the Pope in his latest encyclical, *Fides et Ratio* (nn. 50-52)? One cannot, he says, speak of human reasoning separately from the ill directed uses of reason. Man's reason has been 'damaged', yet it also has shown possibities toward rectification. The Christians least inclined to inform themselves of the Magisterial position on the subject should apply themselves to reading this text instead of speculating about science and philosophy. My personal position on the matter is to dismiss both parties – the scientific and the philosophical.

John Paul II devotes section 77 to 'the work of our critical reason in the light of faith'. This is theological reason. The message is clear enough: reason can be saved only by faith. Yet faith will never be man's province without reason. The contention is far from being ineluctable. Again, the issue is a matter of response to ultimate questions bearing upon sense, truth and being. At all events, we run into the danger of giving rise to a new idolatrous scientism in declining 'to recognize as valid, forms and knowledge different from those proper to the positive sciences, and driving back into the domain of pure imaginings the theological as well as the ethical aspects of religious knowledge' (n. 88). This is no appropriate time to choose stricture in the name of a restricted rationalism.

On Rationality

Josef Ratzinger remarks that it was Augustine who, without the slightest hesitation, assigned Christianity its place within the domain of philosophical rationality as well as natural theology. The synthesis of faith, reason and life used to be a driving power for the Christian penetration of the world. How is it that this is no longer operative to-day at a high speculative level?[8]

Since the rupture caused by Galileo Galilei, physical science has founded a mathematico-experimentally operating rationality that has led to a profound alteration of the very concept of nature. What has occurred has rendered us incapable of achieving an inkling – at the level of intellectual demands – of a direction that could be of any use to our present and most urgent needs, that is to say 'an ethics of universal peace, practical love towards our fellow-men and the necessary means to overstep the boundaries of practical interests'. In this regard the general theory of evolution, which defines itself as the royal road of biology and 'more and more as pri-

[8] J. Ratzinger, 'La foi chrétienne et la question de la vérité', Conference at the Sorbonne, 27 November 1999.

mary philosophy',[9] clearly fails to attempt to remodel the human ethos. Why? Because the ethos of evolution 'ineluctably finds its key-notion in the domain of selection, hence in the struggle for survival by means of successful adaptation, and also in the triumph of the fittest and finally the strongest'.

For the theologian, the status of reason appears to be definable only in reference to that of faith. The use of reason is prior to faith, but with the help of the categorial presupposition of Revelation it can lead to belief. Faith, therefore, is not just an assent of reason, it also brings into play some act of the will.[10] In that case the fullest practice of reason is brought about by reason and enlightened by faith.

In fact, natural reason has been a real problem to all theologians in the latter part of this century, just as it has been to all philosophers. Indeed the very model of an 'emancipated reason' through its bare 'natural light' has flatly failed. When considering reason it is not just the same thing whether one starts from action (like M. Blondel) or from the experience of interpersonal communion (like G. Marcel) or from an affective center of consciousness (as M. Heidegger did).

Philosophical inquiries distinguish several types of rationality. At the same time, positive or natural rights also proceed from a certain type of rationality: the *practical*, if not juridical. Reason, as the faculty of all principles, has no longer to assert itself as being freed from all options of belief. Thus, as regards *critical* reason, its prerequisite for any rational approach is a clear conciousness of the limit that this approach precisely presents in relation to the reality dealt with. As a rule, the philosopher's reason can be thought in *several* directions: the intuitive, dialectic, ontological, hermeneutic, transcendental, without excluding the Thomist model which will retain the value of a regulating concept.

John Paul II refrains from proclaiming neo-Thomism the perennial philosophy of the Catholic Church – on the contrary, he mentions many trends of thought that are more recent and have 'produced philosophical works of great influence and lasting value' (n. 59). *Fides et Ratio* pleads in favour of a philosophical reason that recognized its own capacity for contention against theology. Balthasar was himself convinced that there was no theology without philosophy. Our prevaling mode of thinking has raised faith and reason to a permanent constitutive tension that actuates or will actu-

[9] *Ibid*.

[10] Aquinas, ST IIa IIae q2 a. 1 et 2.

ate the vitality of both philosophy and theology. As a matter of fact, some works related to theological questioning also deal with philosophical issues such as the natural and spiritual worlds, creation, time and eternity, the person. The cognitive modes are clear. Yet, in the typological and epistemic areas not everybody can transgress the boundaries. They are endowed with categorial sense. On the plane of textual immanence there are no gaps so to say – the strictest boundaries concerning the interrogative modes having been delineated as early as their organizing planning out.

Here is an example. Two interrogative modes bring face to face *two readings* of the universe: one can be scientific as the universe is questioned from the view-point of evolution. The other one is religious as it is questioned from that of creation. Man being the only interrogator of his self and the world cannot but ask the question whether evolution, to which he is historically bound, *makes sense* or not. To put both categories together, the proceedings consist in interrogating evolution itself by asking about its sense or no-sense, relating to man within nature from a theological point of view.

Instead of affecting mutual ignorance, or promoting hierarchies in learning, a positive attitude would call for dialogue between partners as subjects facing each other, with a capacity to control any capture and to start its legitimitating process. Then each, from his own categorial viewpoint, would help his partner towards rectifying and renewing himself. Then a better knowledge of the rooting of mankind in cosmos would allow us to understand better the working of the Saviour of the world, and extend his intervention of the category of events in theological speculations: Christ's commitment to saving man enables us to anticipate a new world.

A fairly good convergence is promoted when starting from the viewpoint of the theological categories of Creation and Redemption. The proclamation of Christ's resurrection from the dead implies a specific *Weltanschauung* while it also gives sense and meaning to man's life. In point of fact, it is time for the theologian to take up an evolving vision of the universe under the action of Christ (*in quo omnia constant*).

III. How to Survive Science?

Science is more and more conceived as our best means (if not the only one) to survive. The question in J.J. Salomon's recent book asking 'how to survive science?' is ironical. It bears the stamp of marked ideology. In this respect, it is unfair, needlessly provocative and, undoubtedly, far from being well stated. What is the true situation? Science is not intrinsically dangerous nor are all its effects equally so. Some of them serve man fairly well, bringing hope and enlightenment – the hope of freeing man from diseases, debilating labour or climatic conditions; enlightenment, by providing a space for authentic research into the structure of matter, the cosmos and life. We may take as granted that it may be dangerous because of misdirected effects which escape control in advanced techniques, and in trespassing its own limits when attended by ideological distorsions or philosophical extrapolations.

– Science and ideological distorsions. Science for man? To man, science is an occasion for temptation. The truth about science is that scientific activities cannot escape this temptation of power which runs deep in man. Science gives access to a power which it is hard to oppose. Now, power corrupts and absolute power entails absolute corruption. And indeed one must have a staunch heart to resist such temptation. Contemporary technology is a reducer and destroyer of the person. A reducer whenever it bridles the person's imprescriptible prerogatives, by way of detection by sound or photographs, or by censorial operation. A destroyer, also because of the very diversification of constraints and instruments of torture, or from the deterioration of the conscience and the will due to chemicals whose massive and insidious use has been prompted by the progress of pharmacology.

– Science and philosophical extrapolation. One cannot underrate the critical potency of modern reason. Should science change its view objectively to ultimate philosophy, it would then turn into an extremely dangerous tool, since objectivization outside its proper order can be instrumental in the annhilation of the human in man. Such are the misdeeds of self – imprisonment deprived of mediation.

– According to the theologian, the connexion between science and faith is to be logically derived from the theology of Creation incorporating the origin of evil. Nobody can analyze this connexion without submitting scientific activity, like any other human activity to ethical interrogation. It should be recalled that the limitations enforced upon man's condition by sin do affect all his activities.

Truly another danger threatens, which is more insidious because it is more *intrinsic*. Scientific acts and view-points, in so far as they are human, are bearers of limitation and damage: being objectifiers, they are by nature reducers of realities endowed with the status of objects. The sheer fact of giving an orientation to the scientific eye or act can, under some circumstances, be fraught with ethical consequences. Whether they are 'displaced' in themselves or by reason of their orientation is a point that remains open to discussion: the borderline is not easy to delineate as it is up to scientific theorizing to extend its relevant boundaries as far as possible.

A. Eddington intuitively felt that in the relationship of microphysics with cosmology there lay one of the keys to the scientific intelligibility of the universe. The confession of Creation refers to another mode of assent, tied up with a questioning regime different from the cosmologic pronouncement on initial singularity. Yet the standard model of cosmology speaks for an evolutionary view-point. There is no way to by-pass discussing the importance of the evolutionary theory or the exclusiveness of the positive method as a unique mode of rationality.

This new paradigm, hitherto reserved to the world of the living, is now extended to the whole cosmos. For the purpose of studying nature, the observation principles of quantum mechanics are used, inferring that the universe seems to be set in order to give birth to an observer within itself. The quasi-equality of the larger numbers derives from constants in natural philosophy (c, h, G, mp, H, po, Mu) characterizes a universe inhabited with observers, leastways not incompatible with scientific cosmology and anthropology. From now onwards, this 'anthropic principle',[11] as soon as it is given a finalizing interpretation, will play the role of a criterion between possible worlds. Here the question arises: are we entitled to go this far? Two courses lie open to us:

1) the metaphysical *a parte rei*. One regrets that philosophers are only too ready to renounce the ultimate issue, alleging the crisis of metaphysics (*FR*, n. 56). Then, and then only, the ultimate conclusion permits disclosure of sense *a parte rei*.[12] The anthropic principle alluded to above might well be utilized in its strong form at the borderline of cosmological and metaphysical questionings. But as its interpretation is tied to finality, the universe emerging out of primary undetermination gains access to awareness through the emergence of man at the final stage of human history. An access to attention to the point that this finalizing of interpretation turns it away from science and renews its links to a philosophy of nature and a nat-

[11] Cf. J. D. Barreau and F. Tippler, *The Anthropic Cosmological Principle* (Clarendon Press, Oxford, 1986), ch 7.

[12] G. Martelet, *Evolution et création, Sens ou non sens de l'homme dans la nature,* (Cerf, 1998).

ural theology.[13] While emphasizing intelligibility in the course of evolution, it is argued that its proper cause is the concern of intelligibility and refers to a superior principle of unity.

2) the transcendental way, *a parte hominis*. The Pope has vividly pleaded the cause of a reason that is not afraid of questioning itself (*FR*, n. 27). In *Fides et Ratio* the Pope again pleads forcefully for restoring to philosophy that place – both mediating and propaedeutical in character – that falls to it by right, so that it can cooperate in a regeneration of sense. The theology of creation is not supposed to determine the value of the constant of gravitation. Its critical function is relevant in the field of faith. Philosophy retains a critical function in the field of thought: to manage the articulation of the two orders of reality or discourse in their respective autonomy. Whether it is the hermeneutics or, as I prefer to say, the erotetics of interrogative structures,[14] a decisive margin of initiative is preserved. In front of a purely scientific modelization, e.g. the irruption of mankind within evolution, many views can indeed be supported – a creationist's, an emergentist's, a materialist's – which are not inevitably adequate.

Critical Realism

The only issue for science to face the crisis of sense should be a recognition of its own inner limits in the light of its external limits. Then a reintegration and a re-articulation are possible in the sphere of regenerated sense.

In the relationship of science and faith, when considering the scientific reading from a theological view-point, one can see a recapturing of one mode of interrogation by the other – this recapture being largely unilateral. Were it handled unwarily it could lead to *concordism* and constitute an unacceptable subversion. Concordism referred to by either party – in a fundamentalist sense by theology, in a positivist sense by science – brings about conflict. Man in our days is tempted to reduce himself to a natural being caught as he is in a world ruled by the dominion of death. But religious man shrinks from such limitations on behalf of the other aspects of human identity and rationality to which the scientific approach has not

[13] J. M. Maldamé, 'Evolution et création. La théorie de l'évolution: ses rapports avec la philosophie de la nature et la théologie de la création', *Revue thomiste* n° 4, 1996, 575-616.

[14] Entailing epistemological consequences on the very status of the synthetic theory of evolution: cf. J. Gayon, *Darwin et l'après Darwin: une histoire de l'hypothèse de sélection naturelle* (Paris, Kimé, 1992).

done justice. Inured to *ontological discordism* which concludes to the existence of realities of different orders, it has taken a double truth course. An *epistemological discordism* recognizing differences in textual types and interrogative modes, would be more appropriate, on the condition it finds its own transcendental articulation within interrogative thinking.

The possibility of a regeneration of sense once restored in its transcendentals, allows us to grasp more easily how watchful philosophical mediation operates. I can see here neither concordism nor ontological discordism, only an outline towards *articulation*. This is a renewed form of *critical realism*. Thus to bring heterogenous levels of thought together, negative rules should be stripulated, such as: no omitting of what is still missing; no trespassing on other people's spheres of competence; no affirmation containing incompatibility. I have privileged a transcendental approach in order to argue that my project was to lay a foundation for an *interrogative* theory in scientific research in order to invest science once again with cultural value and hence to establish it within the economy of sense.

According to the philosopher it is essential to replace scientific *research* in thinking. Philosophical mediation manages an interface where all the branches of learning are dynamically related. Concerning for instance, original sin, mediation is in search of an ultimate convergence. Operating as natural philosophy, it remains with it to question to what extension of sense biology or palaeontology have contributed in the constitution of a natural history of man. As religious philosophy, it behaves towards it as an attempt in the light of the Scriptures to discover the significance of man and evil. As theological philosophy, it keeps in view dogmatic contents and Magisterial teachings. The possibility of critical philosophy consists in operating the erotetico-hermeneutical articulation. It should take care not to give rise to any scientism by declining to admit the legitimacy of forms of knowledge different from those proper to positive sciences, throwing back to the realms of sheer fancy theological knowledge together with religious or ethical learnings (*FR*, n. 88).

A way could be opened which allows us to set scientific knowledge and Christian revelation in fair reciprocity. It is only a question of reaching a synthetic understanding of the reality of the world and the destiny of man's innermost self. Following such a course of thought, one endows the recognition of Christ as *Logos* with cosmic extension, in so far as he is the head and fulcrum of the renovated world. It follows that when connecting the theological considerations of man's place in the universe with the renewed version of the world and the emergence of life as imposed by space physics, cosmology and genetics at the turn of this century, one comes across the hope of an eschatological Coming. The present time would be ill-chosen indeed to weaken one and all of our fields of research in the name of a restrictive rationalism. Yes, there are many rationalities in the house of God.

THE FIGHT AGAINST DISEASES: COMMENTS RELATED TO "SCIENCE FOR MAN AND MAN FOR SCIENCE"

MICHAEL SELA

While the main topic of my presentation is science in search of solutions against diseases, therefore a topic definitely concerned with the contribution of "science for men", I want to express my concern about the topic "man for science". We cannot have only science applied to the betterment of mankind, or improvement of technologies: *There will be no applied science if there is no science to apply.*

We have to make science more attractive to young men and women at the start of their careers. We must fight more vigorously against the discrimination of women scientists – and I do not mean "affirmative action". We do not have to lean backwards, just give them the chance they deserve. And we must include in our responsibility as scientists towards society at large the special responsibility towards younger scientists.

Responsibility towards younger scientists

It has been fashionable in recent years for scientists to dwell, both publicly and privately, on the complexity and ambiguity of their relationship with, and obligations towards, society as a whole. In the face of the extreme sensitivity we have all developed as a result, will it be seen as undue temerity on my part to suggest that perhaps there is yet another sphere of responsibility that has been overlooked: that is, the responsibility of scientists towards other scientists? Accountable to the world we certainly are, but what of our bounden duty to the young scientists in our midst, to those men and women whom we have undertaken – as their seniors – to guide, shape, teach and counsel? The fact, I believe, is that, trapped in the maze of scientific administration, puffing and blowing our way over the hurdles we confront in the increasingly competitive race for funding, preoccupied by the need to find solutions for problems such as space and equipment, submerged in the flood of printed and electronic information that inundates our desks, we are no longer as vigilant as we should be about guarding the beacon we have been charged to pass on to those who will follow us in the scientific hierarchy.

Perhaps, therefore, the time has come for us to return to more substantive attitudes towards our own profession. To remind ourselves – for our own sake as well as for that of those who model themselves on us – that science is more than merely one way of earning a living, and with it status. Let us face it: at its best, scientific research is not just another system locked into a larger set of systems. It is a calling. What is more, a calling whose success rests, in the final analysis, on the finest and the rarest attributes of civilized man: on intellectual courage, on hazardous hypotheses, and on the wisest uses of intuition. The responsibility of scientists to the society of which they are a part, and to which they contribute so significantly, is indeed an awesome matter, but should not overshadow other considerations. What has fallen by the wayside, I suspect, may be the responsibility of scientists towards their own tradition, towards the younger generation, and towards the flame itself.

Challenges in diseases

But let me now move to the main topic of my presentation – the fight against diseases. We have desperate situations in which present day science cannot even define the reason for a disease, as is the case for ALS – amyotrophic lateral sclerosis, also called in the States, Lou Gehrig's disease. And, on the other hand, the amazing finding that ulcer is a bacterial disease, caused by Helicobacter, and can be treated with antibiotics.

In neurological diseases there may be hope for nerve regeneration, and there are biochemical and genetic approaches to schizophrenia and paranoia. These will be the developments of the next century, but today the great challenges are Alzheimer and Parkinson, multiple sclerosis and myasthenia gravis. I cannot discuss here for lack of time vascular diseases, but I would like to devote the rest of my presentation to infectious diseases, autoimmune diseases and cancer.

Genetic and immunological diseases

The two important approaches are genetic and immunological. There are 30,000 rare genetic diseases such as cystic fibrosis, muscular distrophy or phenylketonuria. These are usually due to the defect in one gene, and there is a good chance of being able to correct it. But these 30,000 diseases form less than 1% of diseases, whereas 30 major diseases account for the other 99%. In the case of these diseases, both environment and genetics contribute, and the genetic moiety is multigenic and complicated. Nevertheless, a substantial effort is being devoted to elucidate the nature of such genes.

Concept of specificity

As far as immunology is concerned, I want to talk now about the notion of specificity in immune reactions, and their good use for therapeutic and prophylactic purposes. Vaccines are the method of choice to fight infectious diseases, and they are characteristically highly specific. This is due to the fact that substances used for vaccination are close molecular “cousins” of the virus or bacterial toxin that is the “troublemaker”. Nobody expects one vaccine to be efficient for all infectious diseases. While the rate of success is great, we are still faced with those diseases which we are not yet able to prevent by vaccination, and I refer not only to AIDS, but to such old calamities as malaria and bilharzia. Actually, a new danger is tuberculosis: not only that classical tuberculosis is today the killer No. 1 of humanity, because the patients are not treated, but there is more and more of tuberculosis resistant to drugs and antibiotics, and the vaccination approach may be again cogent.

One new approach, possibly of great importance in the future, is DNA vaccination. Instead of immunizing with a protein – or with a mixture including the antigen of importance for vaccination – one isolates the natural DNA and uses it for immunization, with very encouraging results.

Autoimmune diseases

Now, a word about the concept of specificity and its extension to autoimmune diseases and to cancer. We are now extending this concept to autoimmune diseases and to cancer. Whenever it is possible to identify the putative cause of the disease, it should be possible to find a close molecular analog which will combat the disease. In one case of an autoimmune disease, that of multiple sclerosis, we have succeeded in developing a drug/vaccine which has by now been approved by the F.D.A. in the United States, as well as seventeen other countries.

This drug – or vaccine – as I prefer to call it – is a polymer composed of four kinds of amino acids, and prepared so as to resemble and cross-react immunologically with the main troublemaker of the myelin sheath of the brain, the myelin basic protein. This myelin basic protein can provoke an experimental disease – allergic encephalomyelitis, and our substance, denoted by us Copolymer 1, or Cop-1, can suppress the onset of the disease, and in rhesus monkeys and baboons, we showed that it can heal the actual disease. As this is an experimental model disease for multiple sclerosis, we moved to clinical trials. The phase 2 clinical trial was most successful. This was followed by several more big trials, before the FDA approved the drug/vaccine for daily injections for the exacerbating-remitting type of multiple sclerosis. We have proved recently that it can be given efficiently by oral route, and a trial involving 1400 participants is starting now in 9 countries. Copolymer 1 does not seem to have any effect on any other autoimmune disease.

In the same spirit we have approached another autoimmune neurological disease, myasthenia gravis, in which the disease is caused by an immunological attack on the acetylcholine receptor of our nerve cells. We are already successful in preparing a specific drug/vaccine against myasthenia gravis by limited amino acid substitution in two myasthenogenic peptides from the a-subunit of acetylcholine receptor. The analogs formed can heal the experimental myasthenia gravis in mice and rats, and we hope to start clinical trials next year. In principle, in every autoimmune disease in which you can put your finger on a potential candidate causing the disease, it should be possible to produce a close chemical relative that will suppress the disease.

Cancer

In the field of cancer there is an increasing number of tumor-specific or tumor-selective antigens, and therapeutic vaccination may soon become another weapon in the anti-cancer armamentarium, alongside surgery, radiotherapy, chemotherapy and non-specific immunotherapy. From recent reports it appears that even immunization against Alzheimer's disease is becoming a cogent possibility.

One hallmark of Alzheimer's is amyloid plaque, a protein deposit that builds up in the brains of those with the disease. In mice genetically engineered to develop an Alzheimer's-like condition, immunization with b-amyloid (Ab, the protein fragment that forms the plaque) reversed or prevented plaque formation and neural damage. The finding "raises the possibility that immunization with Ab may eventually be used as a treatment, or prophylactically, for Alzheimer's disease".

Globalization

For all these approaches to diseases, we must work together, as one world, globally. Globalization describes trends dramatically and relentlessly, increasing connections and communications among people, regardless of nationality and geography. But globalization without integration leads to a Babel tower. So to improve the health, and I mean first of all the developing world, we need both globalization and the integration of our efforts. And this must be done with great speed, as standing still is the fastest way of moving backwards in a world that is changing at an ever more rapid pace.

SOCIETY IN THE FACE OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT: RISK, DECISION, RESPONSIBILITY

ANDRÉ BLANC-LAPIERRE

The evolution of science and technology – and of their interactions with the general life of society – have accelerated tremendously over the past few decades.

Science has had a strong influence on the history of humanity: on the one hand, by clearing man's access to a better knowledge of the universe and improved understanding of its mechanisms, and on the other, by placing at his disposal the means which, by way of the development of techniques and technologies, have revolutionised living conditions.

The *growth in knowledge* is unequivocally a good thing which becomes part and parcel of cultural development. The same does not apply to the *usage of the means* generated by this knowledge. Humans can indeed use these for good, but also, unfortunately, for evil. Side by side with the immense *progress* achieved, for example, in systems of communications between people (in transport, telecommunications and so on), in agriculture, health, in the production of energy and materials, great harm on just as enormous a scale results from the increased efficiency of the means of destruction. The *risk of diverting knowledge and new technical prowess towards evil*, when they can be otherwise bring progress or are even primarily developed for such progress, undoubtedly exists. But there is more to this. *Any construction or accomplishment* (for example, large public works projects, means of communication, energy production developments, even medical operations and so on) *entails a risk*. *Any action entails a risk*. Taking the point to the extreme, *anything produced involves a risk* (it is the dose that makes the poison!). Man has been confronted with risks since time immemorial (floods, epidemics, earthquakes, wars and so on). However, with industrialisation and factors like the concern to take accidents at work into account or the development of insurance, and, moreover, with changed attitudes, today the notion of risk takes on an increasing importance in daily life, in everyday concerns and in the media, and, with the veiled disquiet induced by present day crises, society's very conception of danger is changing. True, there are indeed objective grounds for all this, but also showing through is a loss of confidence in the future. However, many signs should be leading us to look on this in a more optimistic light. To cite just one example, life expectancy which in part takes account, at the population scale, of the whole range of attacks to which it has been exposed, has risen spectacularly since the beginning of the century.[1] The corresponding epidemiological data are not well known to the public and there are many who believe that the general level of health has been adversely affected by repercussions from technological activities whereas in fact it has never been better. The overwhelming majority of harmful effects on health are, at least among the French, linked to behaviour (lifestyle, tobacco use and so on) and not to the environment in which they live. Here I quite happily quote Maurice Tubiana:

> All innovations, whether they concern technologies, food or products, and also behaviour and practices, are today subjected to constant criticism which weakens decision processes and destabilises the decision-making powers. What in this criticism are the relative weights of uncertainties and indisputable facts? Is it a consequence of a growing trepidation among people or does it result from the rise in power of a certain number of counterbalances? Does it stem from advances in prevention, which mean that the smallest anomalies are now detectable? Or, again, does it come from new principles for action elaborated in order better to preserve the living environment of future generations?[2]

For my part, I am convinced that the current feeling of disquiet, pessimism, and the malaise created by an emphasis on the immediate rather

[1] I refer to 'Risque et société', edited by M. Tubiana, C. Vrousos, C. Carde, and J. P. Pagès, *Symposium Risque et Société* (Nucléon, Paris, 1998). See p. 24:

Life expectancy at birth

1900		1980		1997	
M	F	M	F	M	F
44	45	70.2	78.4	74.2	82.1

[2] See (1) above and (2) M. Tubiana, *L'éducation et la vie* (Editions Odile Jacob, Paris, 1999).

than on the future, essentially results, for many of our contemporaries, from a loss of solid references such as religious, moral, family or national ones.

If we stick to everyday language, the notion of risk is quite simple. It bears on a potential danger, a potential peril, that could result from a given action envisaged that would or would not be given the go-ahead. To varying degrees, people will count on *beneficial* effects and fear *unfavourable* consequences. Put in this straightforward way, certain comments or questions arise.

Are the *benefits and risks clearly set out?* Has the presentation so expounded been arrived at through a process of *rational reflection* properly conducted and founded on *established experimental facts?* Or does it come from the attraction for *short-term gratification* without taking account of *medium – and long-term – consequences* (the pleasure of driving at high speed, drugs and so on)?

Is it a question of an *individual decision* within the reach of the individual or of a *collective decision* involving public powers (as in for instance the construction of large infrastructure projects, or health policy)? The probabilities brought into play will not be the same; I would even go so far as to say that, in the second case, on condition that certain thresholds are respected regarding the protection of individuals, the decision maker will work more on mathematical expectations focused on the community level rather than on individual probabilities. In the case of decisions that must be taken regarding projects affecting the community, it must be realised that, even if technical feasibility studies are conducted with the greatest care and lead to clear conclusions, there remains, for them to materialise, a stage which takes into account *economic* (cost, viability in competition with other projects and so on), *social* (such as people's wishes, acceptability by society), *political*, *moral* and other considerations. In this process, the roles of each actor – scientist, expert, politician and citizen – should be distinguished, although evidently one person may have more than one role. As Jean-Yves Le Déaut, Chairman of the Parliamentary Office of Assessment of Scientific and Technical Choices (France), has said, the politician's responsibility is a particular one: 'There is limited room for manœuvre: a policy of *prevention* (when the danger is known), even though necessary in the greatest number of departments, is neither possible nor sufficient. There are constraints that could hold a decision in abeyance: scientific knowledge on a subject evolves very rapidly; at the time when a decision must be made, this knowledge is not fixed. The time for action is short, with set limits; the time-scale for acquiring scientific knowledge is very long, expanded and "hard political decisions must be made on soft scientific certainties".'[3]

It is in order to handle these uncertain situations that the precaution *principle* was developed. This appeared on the international scene at the moment when fears were first expressed about *climate changes caused by the greenhouse effect*. The Rio Declaration of 1992 stipulated: 'If there is a risk of serious or irreversible harm, the absence of absolute scientific certainties must not be used as a pretext to postpone the adoption of effective measures aiming to prevent degradation of the environment.' France is one of the few countries to have introduced this principle into its legislation. The Barnier Law of 2 February 1995 on the strengthening of environmental protection stipulates that 'the absence of certainties, taking account of scientific and technical knowledge of the moment, must not hold back the adoption of specific measures, taken in proportion, aiming to prevent risk of serious *and* irreversible damage to the environment for an acceptable economic cost.' There is a certain discrepancy here between the Rio Declaration which talked of serious or irreversible harm and the French law which says serious *and* irreversible. In addition, the Barnier Law states that the cost must be economically acceptable and recommends that the measures to be taken should be in proportion to the risk. Such proportionality would necessitate an assessment of the size of the risk and the cost of the measures.

These aspects could be discussed in order to gain a perception as to whether, given the scientific uncertainties that exist and the need for research and for additional observations, to which no definite lengths of time can be attributed, the precaution principle is a *legal* principle, an expression of *common sense* or a *rule of ethics*. It seems that depending on the classical approach founded on the link between scientific knowledge and action, the idea of precaution should, at Rio, have led to two decisions:

1. To extend to their maximum potential scientific studies on the relations between human activities (production of CO_2 and other greenhouse gases) and climatic modifications.

2. To study the means of production of sizeable quantities of energy without carbon dioxide emission and to encourage them.

In all cases, 'zero risk' does not exist, and one is still made to wonder if

[3] 'Political Responsibility in the Face of Risk Management', 'La responsabilité politique face à la gestion des risques', paper by Jean-Yves Le Déaut, symposium *Risque et Société*, mentioned in (1). See p. 264.

a risk is acceptable considering the anticipated *benefits*. But *what is meant by acceptable risk?*[4]

This is a complex question: a *government* that decides on large infrastructure projects (for energy, transport, civil engineering works and so on) is not in the same *position* as a *judge* who has the duty, some years later, of declaring a verdict on a question (a lawsuit or complaint before the courts) involving a development of that kind. Let us briefly analyse this point.

In the first case, the notion of *risk* is linked to the idea of *choice*. Before the final decision is taken, it is essential to define all options that could possibly be suitable. In a given situation, or confronted with a given problem, these are:

– To do nothing, let the situation 'rot' and take its natural course. Whether deliberate or the fruit of a certain unconscious passiveness, this attitude is indeed a choice in the sense that it will leave its mark for the future and there will be *consequences*.

– To weigh up several different solutions. Each will have its attendant *hope of benefits and fear of risks*. It makes no sense to fix attention only on the benefit and risk relative to just one of the possible solutions: they must be compared with benefits and risks associated with other solutions, not forgetting the one that entails doing nothing. Before proscribing a technology in order to eliminate the risks, the question must be asked if, by doing so, we are not condemned to accept another at least as dangerous, if not more so. For example, an unreasoned hostility to nuclear energy must not be allowed to obscure the fact that coal burning liberates carcinogenic products and intensifies the problem of carbon dioxide.

Risk-benefit analysis is made more difficult as the number of highly diverse factors increases: advances anticipated, people's safety, economic repercussions, acceptability among the populations concerned, and so on.

Moreover, it has to be noted that a quest for ever increasing *safety* in a given field in the end generates costs which rise extremely rapidly (safety has no price, but it has a cost!) and, beyond a certain degree of safety, it is reasonable to wonder if it would not be preferable to allocate additional sums to other needs of humanity, for example to other domains where safety is less well assured.

[4] On the notion of acceptable risk, here I am taking up again and adding to some ideas I aired during the 1996 Plenary Meeting of the Pontifical Academy of Sciences in a paper entitled: 'Science and Society – Reflections on the Evolution of their Interaction and on their Consequences for Culture and Education'.

A point which appears to me essential is that the choice made at the moment the decision is taken, even if it results from the then most objective and far-reaching study possible, will only prove itself to be a good one if the processes it sets in train are watched rigorously so that the conditions required for it to run smoothly are constantly met and the safety rules enacted are continually updated so that benefit can be gained from experience.

In the second case, involving the judge, the situation seems to be different because it does not entail comparison between several possible policies in order to choose one, which, rather, is the domain of the legislature and executive authorities. Instead, it involves saying if, in the actions carried out, the law has been complied with, the regulations observed, the official safety standards met, and whether or not the people involved have fulfilled the duties assigned to them among their responsibilities or could, instead, be guilty of professional misconduct.

In order to make a judgement on an action, it is absolutely essential *to base deliberations on scientific and technical knowledge as well as on the corresponding legislation in force at the moment of the action, not at the moment of judgement.* As for the issue of 'precaution and law of responsibility', I think it important to quote from a text by Marceau Long, Honorary Vice-President of the Conseil d'Etat, (which is taken up again in that Council's report of 1998): 'I am, for my part, sensitive to all that precaution brings to us. My personal conclusion is, however, that even if it is incorporated in the legislation, it is still only a political principle. Although precaution does not protect us completely from risks, it can sometimes allow us to escape from them, or much more often to avoid or soften their harmful consequences. We have to be careful not to derive from it too hastily the converse of the principle: if harm has been done, there has been a lack of precaution, and avoid making from this a foundation of responsibility.' It must not be allowed to happen that according to a notion of '*responsibility without fault*' someone might be responsible for what he *had to know*, which is quite usual, but also for what generally *had or should have been suspected*.

Let us come back to the *probabilistic* aspect of risk. In anything that is realised there exists a 'residual' risk 'due to chance' resulting generally from the chance succession of unfortunate events, each one haphazard in itself, none of which, most of the time, are particularly serious, but which, happening altogether, can lead to a disaster. It may be that if just one of these events were not to occur, that would be enough to preclude an accident. Quite astonishingly, *probabilistic risk analysis* was developed only in the early 1970s, with the report of N. Rasmussen, of the US Nuclear Regulatory

Commission. This report drew up the first general analysis of nuclear power stations. It examined a very broad spectrum of possible accidents, given the probabilities of occurrence of corresponding scenarios, and assessed the repercussions. Probabilistic methods have been applied in a great diversity of fields. They bring into play the systematic study of *fault trees, accident initiators, status graphs and so on*.

A certain reserve that could be termed 'popular' has emerged concerning probabilistic methods. This, generally speaking, results from two kinds of reasoning.

On the one hand, the notion of probability is not always well grasped. On tossing a coin, if we have found heads 100 times, we often think that tails will come up – and in doing so forget that, as Joseph Bertrand put it so well. more than 100 years ago, 'the coin has neither *memory nor conscience*'.

Another, deeper problem comes from the fact that the accidents that are considered correspond in general to very small risks: their *probability* is very small and the notion of *frequency*, much more meaningful than that of probability, is practically inaccessible on the scale of a human lifetime.

Among the specialists, much attention is given to the following point. Work is performed on *models*, for example models of existing nuclear power stations, whose operation and safety we want to monitor more effectively and improve, and for which we have feedback from experience, or models linked to 'virtual power stations' if there is a question of new installations being planned. Naturally, these models must be improved continually and it is, in particular, essential to make sure with the utmost care that one has not considered as independent certain faults which are in fact linked. The probability of finding oneself faced with the simultaneous faults of three *independent* organs each having a probability of 10-3 is 10-9. On the contrary, if these three faults are a *consequence of* each other, this probability stays at 10-3. This is the problem of the screening of all problems of common origin, associated with the breakdown of shared feed systems, or with a fire, and so on. At present, on passenger aircraft each hydraulic control system is installed in triplicate. It is clear that the considerable gain in safety resulting from this *redundancy* would be cancelled out if they had a common feed mechanism, the failure of which would paralyse the systems simultaneously.

What is the significance of the probability values that result from the probabilistic analysis? What, for example, is meant by saying that the probability of a total loss of control of an airliner is in the order of 10-9/hour? It must be realised that such figures are linked to the study of models, which makes them more of relative value, even if these models are, as it happens, improved unceasingly by feedback from experience. However, if, by using the same model, we gain a factor of 10, we can admit that the safety has by the same token increased by a factor of the same order. In this way, the analyses that entail the use of these methods are important as starting points for improvements in safety.

The various people involved in decisions regarding the problems already referred to are all, to a varying extent, confronted with the notion of *responsibility* in the broadest sense of the word, not only of *justification* if afterwards they are called to account in the courts, but also of *action* in the sense of an objective to achieve, of an advancement to promote, or of a *mission* to fulfil. The responsibility can take a variety of forms depending on the nature of the question it relates to: the *responsibility of the 'scientist'* if it is a question of declaring on the state of the science involved; *the responsibility of the technical expert* for equipment and installations; *the responsibility of the judge* who applies the law; *the responsibility of the politician* who has to govern while taking full account of several aspects such as budgetary, sociological and international situations; and, of course, *the moral responsibility* from which nobody can be exempt. Naturally, one and the same person may be vested with more than one of these responsibilities at once, to varying degrees. The need for the clarity of a situation and well-prepared decisions, however, calls for a precise unambiguous description of the mission assigned, in the name of the knowledge and skills, and in virtue of the mandate, through which each player expresses himself. If a politician calls on *the expertise of a scientist and a technical specialist*, the latter must brief him on the state of current scientific and technological knowledge, possibly on the uncertainty attached to this knowledge, and on studies that could reduce this, while holding back on any input related to his own philosophical, political or other points of view. Naturally, the person who has the duty to decide must combine the arguments advanced by the scientists and technical experts with input that bears on economic, political, social and other motivations. He takes the decision and is responsible for it. The part played by each actor is thus defined, transparency is possible, and, probably, the decision is made under favourable conditions, with the responsibilities of each of these 'agents' clearly marked out.

To finish, I would like to stress the role that the scientific community, the universities and the Academies of sciences should play, *without compromising on the fact that risks are real or that they should be assessed in a reasoned way*, in assuaging the excessive and often irrational fears currently expressed which, indeed, can paralyse any zest for research and enterprise. The role seems to me to be a dual one:

– on the one hand, *to enlighten public opinion* on the exact current state of up-to-date scientific knowledge available that is relevant to large projects underway by scrupulously distinguishing what science can and cannot say and by indicating what types of research could improve this knowledge. This contact with public opinion can pose problems for scientists because high levels of ability to explain and instruct are needed to find a common language, but it is essential to make the effort;

– on the other hand *active participation is needed in training young people, either directly or through their involvement in elaborating study programmes*. I believe that it is essential, in today's world, to develop experimental sciences to develop contact with real situations and, also, to cultivate a critical mind to enable people to sift and make proper sense of the enormous mass of information, truths and counter-truths which surge onto the scene.

I still believe that our young people are not put into contact early enough with the notion of *probability*, by which I mean the deep sense of what probabilities, statistics and related conceptions really are.

I have no doubt that if 'probabilist culture' was more widespread among the public and in the media, there would be less talk of the mysterious 'serial law'. This translates the idea that a catastrophe is not an isolated event in time. That could be described in considering the models that envisage the intervention of catastrophes occurring at random instances (Poisson) such that each of these instances would be associated with a cluster of concomitant catastrophes happening in a short period of time.

It appears to me highly important that students who do not intend to enter the scientific professions (aiming for fields like law, literature, the arts, medicine or the media) should receive the benefit of a good grounding in the processes and methods of science, incorporated into their courses, in the same way as they do for the development of their own culture. This does not mean going through in detail for them any particular chapter of science, but enabling them to capture the essence of scientific thought, of the way it has evolved, and its integration in the general body of knowledge.

Finally, in closing, I would like to stress one important point. That is, the weight which is attached to the problem of a rational assessment of risks in any action which is undertaken in the interest of ensuring a *development which is sustainable.*

CHALLENGES FOR AGRICULTURAL SCIENTISTS

TE-TZU CHANG

Historical Perspectives

Since the dawn of civilisation, advances in agriculture have played a pivotal role in allowing on-going progress in human well-being and human pursuits. Without a filled belly, no civilisation can flourish and achieve continued progress. Contributions by agricultural scientists have served to fuel dramatic advances in the supply of food, fibre and other basic necessities by applying Mendel's law of heredity, the combined use of water, fertilisers and pest control, and labour-saving machinery in large fields. The underlying knowledge for such scientific innovations has come from the natural sciences, especially biology, together with engineering, and the experience and initiatives of farmers themselves

Until recent decades, scientific innovations experienced widespread use in the developed nations but much less so in the developing countries. Meanwhile, total human population has risen from one billion at the beginning of the twentieth century to over six billion in late 1999. Of these about three billion have been added since the end of World War II. Food production remains inadequate in the developing world where a high proportion of the population remains under-nourished. The history of continued progress in agriculture has been the product of a true integration of technology, science and human endeavour. These processes have amply demonstrated the importance of the inter-dependence between scientific disciplines and demographic factors.

Achievements in the Developing World over the Last Three Decades

Since the early 1970s, giant strides in food production have been made in the developing world, in particular in rice and wheat, in what is widely known as the 'Green Revolution'. Not only was the spectre of the predicted widespread food shortage of the 1970s averted, but calorie intake *per capita* has been appreciably raised.

Recent estimates calculate that about 78 percent of rice land has been planted with modern varieties; the corresponding figure for wheat is about 60%. In the year 1992-93, rice yield was nearly double that of 1961; for wheat, a gain of about 60% was achieved.

Yield increases in rice and wheat scored an annual growth rate of about two percent during the period of 1970-90, but the growth has slackened sime 1990 and the yield potential has remained the same since the late 1960s. Further advances in wheat and rice yields have also slowed down in recent years. During the same period, other cereals and root crops have also scored production increases but they have been less dramatic than is the case with rice and wheat. The massive US food aid programmes have disappeared.

The Human Factor

While the role of scientists has been emphasised up till now, we should not overlook the essential human attributes in these processes: dedication, pride, perseverance, and incentives. Agricultural research has been discouraged by the low respect and poor incentives accorded to its research, educational, and extension groups. Even more important is the less than equitable returns on the toil of farmer. Unless we attack the roots of the malaise, food insecurity will be the primary destabilising event on a grand scale during the twenty-first century. Its damaging consequences and ramifications will also affect the developed nations.

When scientists of all professions come to grip with the realities of the uncertain future with an eye on the plight of the under-privileged rural population, they will be in a better position to further the benefits of science and attract more young men to pursue scientific endeavour. Indeed, man and science are intertwined and are inseparable parts of scientific advance. Continuity is the essence of progress.

Rising Constraints in the Twenty-First Century

A number of wide-ranging and widespread constraints lie ahead. Productive land is on the decline due to competition from industrial and housing development, highway-building projects, and soil erosion. New irrigation projects have been installed with high costs and low local investment. Old projects are increasingly silted and in poor repair. Good quality water is becoming scarcer and more costly. Region-wide climatic aberrations have upset the stability of rainwater supply. Above all, the escalating rise in food production costs, poor returns from declining crop commodity prices, and the shortage of labour on farms, have all discouraged farmers from investing in increases in production. The dwindling supply of both natural and human resources has lowered the scale of vital improvements and on-farm experimentation. Most governments and urban communities are neglecting the primary food-producing sector. Meanwhile, the world's population continues to grow at burgeoning levels, although at a slightly lower rate than that envisaged by previous predictions.

Centres of modern and intensive production are beginning to face the aftermath of overly intensive cultivation: pest epidemics, soil degradation through erosion, salinisation and alkalisation, and the pollution of neighbouring areas.

What and how much Can Agricultural Scientists do?

While agricultural scientists will again bear the primary responsibility for dealing with a long list of daunting challenges, all sectors of society and the international community must mount an all-out and co-ordinated campaign to cope with the problem of food security on a global scale before serious food shortages suffered by an impoverished and populous planet grow into civil strife and international conflict. The basic element in enabling food supply to meet increased demands and expectations is of such paramount importance that it cannot be lightly treated as mere routine business. Research, educational and extension groups need to work together to sharpen their focus; and they should work together for a common cause. Agricultural scientists themselves need to re-assess their strength and weaknesses in order to redirect their strategy and logistics, and thereby recapture the momentum of the past decades. The necessary moves proposed are as follows: (1) a return to, and improvement of, the 'bread and butter' type of productive research which has suffered greatly from the heat waves of biotech; (2) an exploitation of the merits of biotech, but with due consideration of related issues such as ethics, intelligence property rights, bio-safety, and social justice; (3) more mission- and field-oriented-young researchers/workers, who need to be trained and supported. Above all, inter-disciplinary and institutional collaboration must be further strengthened and implemented. Agricultural scientists must respect and use the expertise, initiatives and experience of farmers and enrol the latter as partners in field research. Farmers are no longer an ignorant and passive sector. Enhanced education in rural areas will elevate their standing and representation in society.

Thus, the synergism of science and man can be reaped to mutual advantage. Such an interaction will enable us to deal with this urgent problem in time.

REFERENCE

Papers by T. T. Chang, P. Pinstrup-Andersen, and D. Byerlee *et al.*, in the 1999 P.A.S. Study-Week entitled “Food Needs of the Developing World in the Early 21st Century”, 27-30 January 1999, the Vatican.

THE MATHEMATISATION OF SCIENCE

LUIS A. CAFFARELLI

I was asked to make a short presentation on trends and directions in mathematics.

Mathematics has become a vast subject, with different techniques and scientific values. Even in a confined area like fluid dynamics, the same subject, say the Navier-Stokes equation, has a different connotation for different research groups (compressible versus incompressible, formation of singularities, zero viscosity limits, etc.)

I have chosen therefore to:

a) Stay very close to my area of expertise, non-linear analysis, partial differential equations and applied mathematics, where I could better present the issues.

b) More than a determined aspect or evolution of a theory, to discuss several examples of a trend that I feel will have enormous importance in my area of mathematics, as well as in our relation to the rest of the sciences.

The main theme of my examples will be that science and engineering are requiring the development of very sophisticated mathematical theories.

The enormous computational capabilities that are becoming available year after year have allowed scientists not only to look at more detailed models of existing physical phenomena, but also to be able to simulate complex materials and processes to optimize their design properties.

The first area I would like to discuss concerns mathematical development in image treatment (storage, enhancing, and compression). For simplicity, a black and white image simply means to provide a function (the grey scale) that may be piecewise smooth with sharp transitions, or dotted with very fine dots, or blurred and imprecise. Nevertheless, the eye has a special ability in grouping the essential features of it and reconstructing out of it a familiar image.

The first development that I would like to discuss is the theory of wavelets, which has to do with a way of extracting from a picture its detail up to a given level, and allowing us to reconstruct it (see Pictures 1, 2, and 3 Brushlets).

In trying to do so, there are two conflicting interests, very common in physics and mathematics sciences: size and oscillation, i.e. the choice between intensity and contrast.

Mathematically, this means having to choose between an approximation that averages in space, or one that averages in frequencies.

Averaging in space (a finite element discretization, for instance) will lose the detail in the oscillations; averaging in frequencies loses the local spatial detail. The representation of a function as a superposition of sines and cosines (the computation of the Fourier coefficients) depends globally on the function, although it attempts to represent it pointwise.

The compromise solution has been the development of wavelet theory. Wavelets are *bases* families of elementary profiles for decomposing function, intensity in our case, that are localized simultaneously in space and frequency.

In fact, they are *telescopic* both in space and frequencies, in the sense that they are:

a) Layered in space. There is a layer of size one, one of size 1/2, 1/4, 1/8, etc.

b) Layered in frequencies: they are mostly concentrated between frequencies 1 and 2, 2 and 4, 4 and 8, etc. (In fact they can all be constructed by translating and diadically shrinking a single profile, the wavelet) (Picture 4).

Wavelet theory has found deep applications not only in image compression but also in fluid dynamics, as well as classic harmonic analysis.

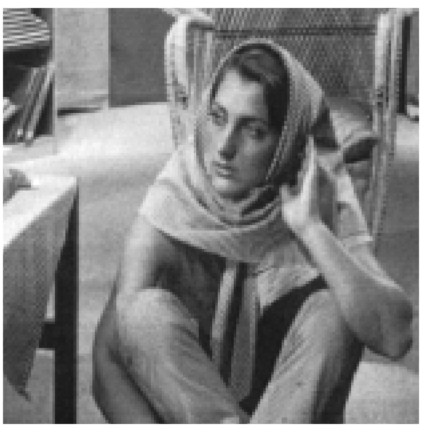
The other mathematical tool developed due to the needs of image treatment concerns geometric deformation and evolution.

In the same way that wavelets address an issue of multiple scales, geometric deformations address an issue of multiple models (Pictures 5 and 6: plane and geometric picture).

The issue is: given a blurred or a spotted, noisy image, how can it be grouped in order to make it a recognizable object. The idea, a classic one, borrowed from phase transition theory, is to assign to every configuration an energy that combines its closeness to the given, disorganized image and its degree of “organization”. (For instance, if it is a curve enveloping a region, its length.)

Next, one lets the configuration “flow” towards its energy minimum. For instance, a curve will evolve trying to minimize a combination of its

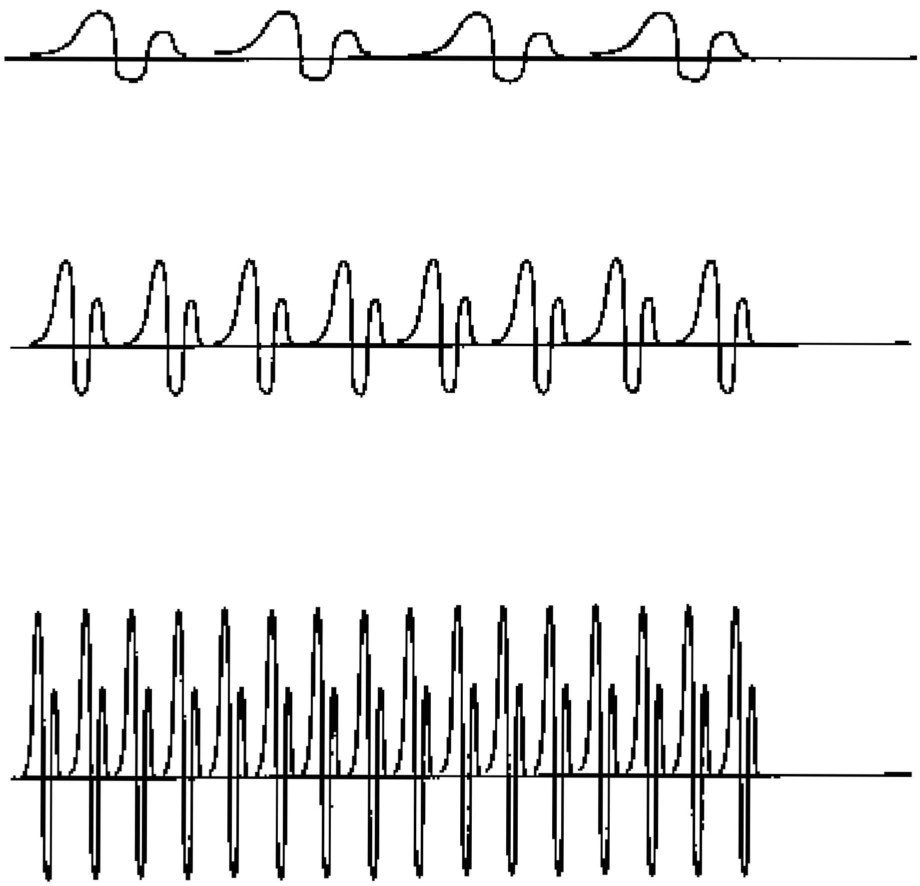
Picture 1 – 8:1 Compression



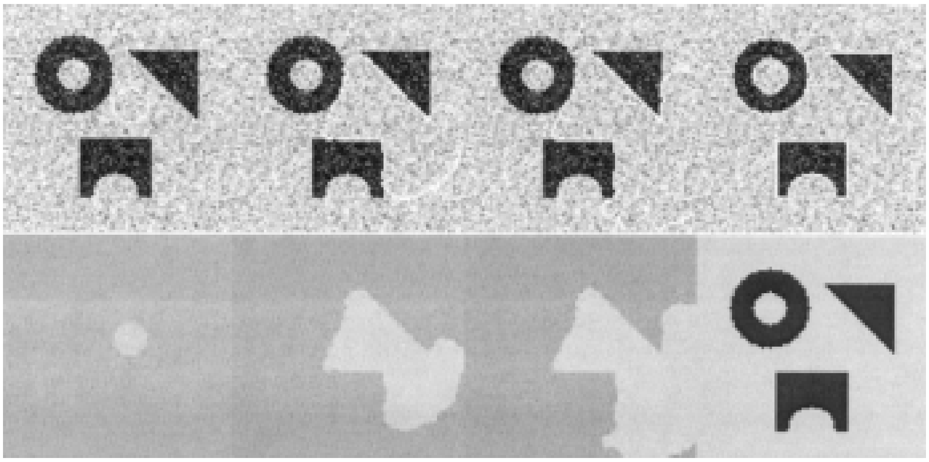
Picture 2 – 16:1 Compression

Picture 3 – 128:1 Compression

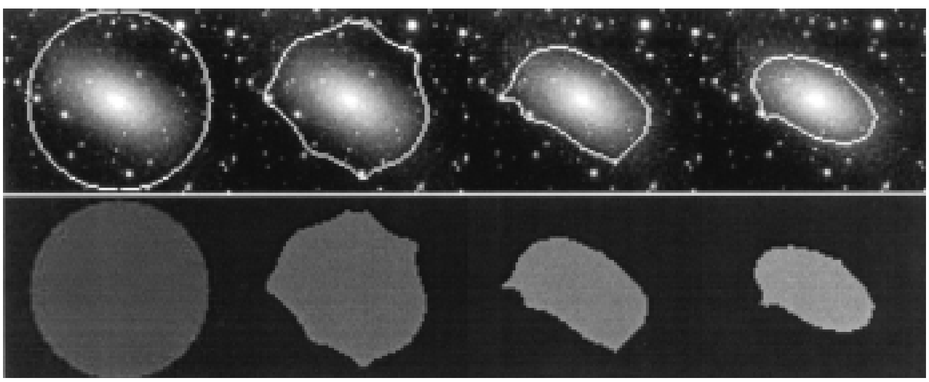
Pictures 1, 2, 3 – Brushlet Pictures. Yale Wavelet Computational Group.
http://www.math.yale.edu:80/YCM



Picture 4.



Picture 5 – Results for a very noisy image, with the initial curve not surrounding the objects. Top: u_0 and the contour. Bottom: the piece-wise constant approximation of u_0.



Picture 6 – An Active Contour Model without Edges

Pictures 5, 6 – Chan, Tony F. and Luminita A. Vese. “Active Contours without Edges.” *IEEE Transactions on Image Processing.*

length and the intensity it encloses. When one tries to do that, singularities arise, and as the structure of the "approximate" configuration deteriorates, it is necessary to go to a higher model. For instance, a "field theory model" that adds "artificial viscosity" or diffusivity to the surface movement, to resolve the singularities.

For computational purposes we have thus a *multi-model* theory, where in areas of "normal" evolutions we use simpler geometric evolution, but couple them with higher complexity models to resolve singularities in the flow. The issue is, of course, when to use each model and how to couple them.

The issue of matching different models is a very important one; we will see another example later.

Next, there are two examples that come from continuous mechanics and one is multiscale, the other is multi-model.

The multi-scale concerns homogenization (see Pictures 7 and 8). Typical examples of homogenization are composite materials, or flows through layered rock formations.

Fluid or gas through a porous media, for instance, can be studied at several scales: at a few centimeters scale, the structure of the pore and the capillary properties of the fluid enter into consideration. At a few meters important factors are soil layers, large cracks, etc.

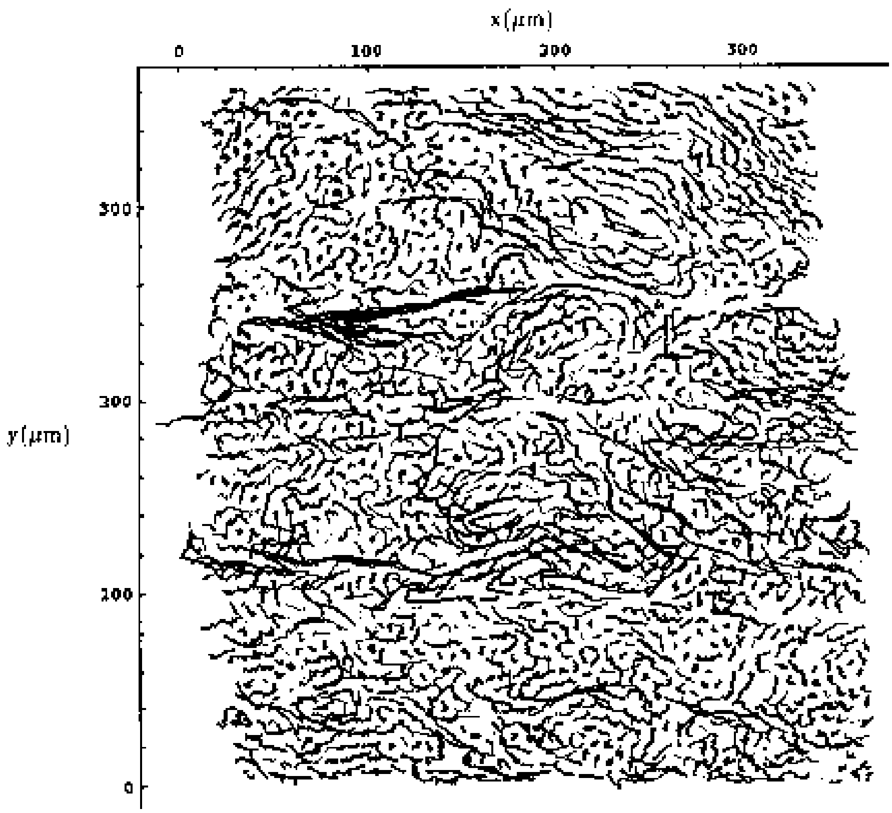
The interest, though, centers mainly on trying to simulate reservoirs at kilometer scales.

One must, therefore, model the interplay of each of the scales. At a kilometer scale, for instance, flow laws are much simpler, but the parameters (effective constants) or the non-linearities in these laws depend heavily on the small-scale behavior. Homogenization appears in many areas: elasticity, crack propagation, etc; and involves very sophisticated tools of non-linear analysis and probability theory.

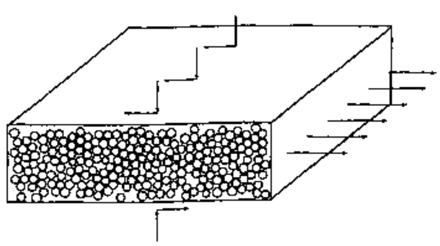
The last example comes independently both from aerospace engineering and semiconductor design. In terms of aerospace engineering, a typical example of the problem can be described as follows: a jet fired in an atmosphere of very low density goes from a very compressed regime to a very low density one in a length of a few meters.

According to its local density or density gradient there are several classical models of gas dynamics.

The continuous model, where densities are relatively high and shocks are weak, assumes that the gas moves locally in a coherent fashion, that is, there is locally a bulk velocity, one of our unknowns responsible for the flow.



Picture 7 – The centers of the 2000 fibers in 15 crossections 50 μm apart. All these centers are depicted in the figure which shows the movement of the fibers in the *z*-direction.



Picture 8 – Model problem for a unidirectional composite.

Pictures 7, 8 – Babuska, Ivo, Borje Andersson, Paul J. Smith, and Klas Levin. "Damage analysis of fiber composites." *Computer methods in applied mechanics and engineering.* 172 (1999) 27-77.

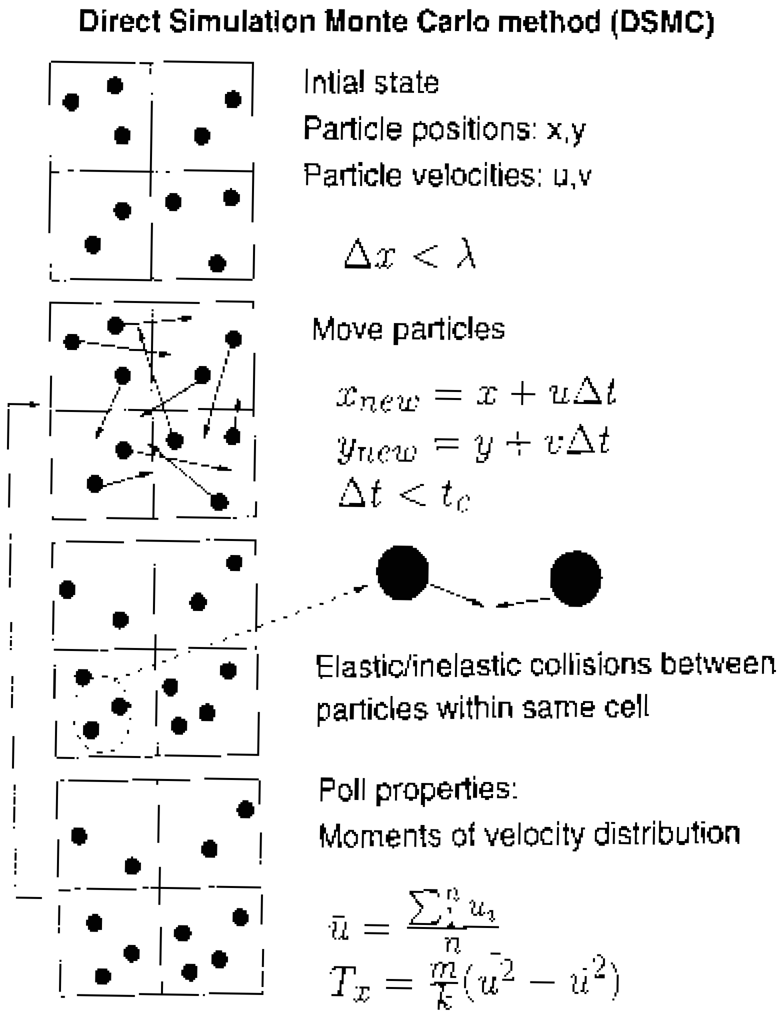
For lower densities, when particles spend a non-negligible time traveling before hitting each other, there are transport models where at each point in space there is a density of particles having a given velocity vector (so now, your ambient space is position and velocity) and colliding laws are prescribed.

Finally, there is always a basic computational model, called the Montecarlo simulation: just give a bunch of particles, with initial position and velocity, prescribe a "bouncing" law and see how they evolve by following each one of them (Picture 9).

This is, of course, the closest model to the "truth", but computationally very restrictive, so the issue is to use it only in those regimes where previous approximations fail.

How to match these three models is a central issue in continuum mechanics, since obviously the Montecarlo method is a simple fundamental way of modeling from granular dynamics to charged particle flows in semiconductor devices, but one would like to (correctly) transform it into transport or continuum approximations whenever possible.

The mathematical issue is, then, as density increases, what is the simplest proper transport model corresponding to a "bouncing" law, and further for higher local densities, the simplest proper continuum (hydrodynamic) model corresponding to the transport one. And, of course, how to couple different regimes (Pictures 9, 10, and 11, see p. I).



Pictures 9, 10, 11 – Roveda, Roberto, David B. Goldstein, and Philip L. Varghese. "A combined Discrete Velocity/Particle Based Numerical Approach for Continuum/Rarefied Flows." AIAA Paper 97-1006, Reno, NV, January 1997, (see p. I).