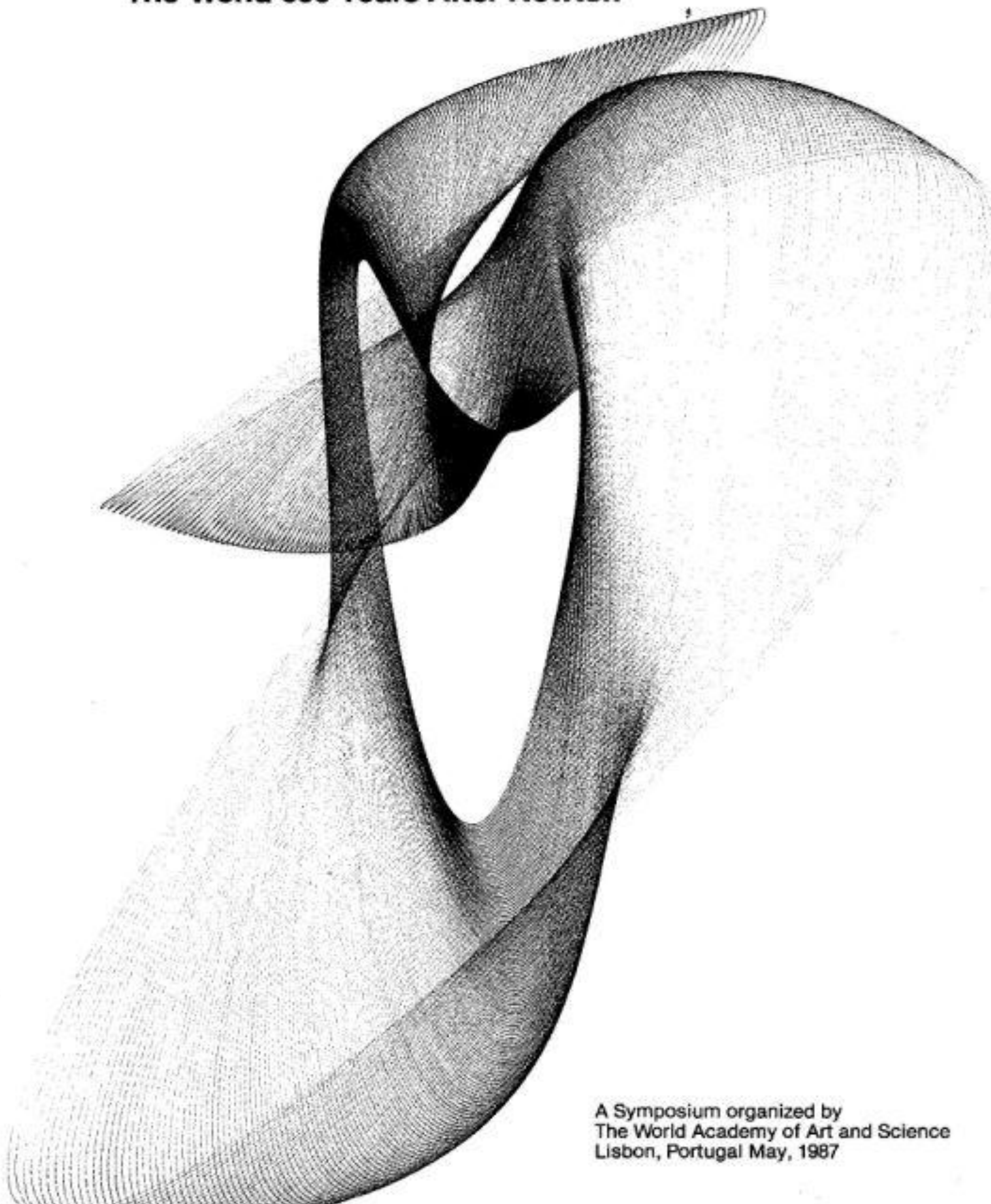
NEW PARADIGMS

The World 300 Years After Newton



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NEW PARADIGMS

THE WORLD 300 YEARS AFTER NEWTON

Proceedings of a Symposium

at the

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Organized by

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Editor

Sam Nilsson, FWAAS

Foreword
by
Sam Nilsson

Few theories have had such a profound influence on society as that published in *Philosophiae naturalis principia mathematica*, by Isaac Newton. The book was presented to the Royal Society in England on April 28, 1687, that is, 300 years ago. It was the culmination of an unprecedented creative process which established the (then) 'new science' for mankind.

In the 300 years that have passed since the publication of Newton's work, scientific method has become so powerful a way of thinking that its principles have often been applied even elsewhere, leading to new modes of thinking about humanity, societies, economics and politics.

Harlan Cleveland says of Newton's *Principia* in his contribution to the Lisbon Symposium that:

> "The logic is linear and mechanistic. As we decipher the riddles of nature, we must naturally give thought to the technologies the new science makes possible; because the new technologies are possible they also must be necessary; if the new technologies enable us to make new machines and processes, we must actually design, construct and deploy them."

This linear logic is now on trial by scientists, artists, spiritual leaders and indeed by the public in general.

What could be more natural then for a 'World Academy of Art and Science' than to celebrate the tercentennial of Newton's *Principia* by a symposium at which artists, scientists and other scholars would have the opportunity to discuss the 'ending' of the mechanistic paradigm and the emergence of a new logic. The idea of such a WAAS symposium in connection with the general assembly meeting was born in June 1986 at the summer cottage of the president, Carl-Göran Hedén, which lies sufficiently and appropriately distant from the urban linearities of Stockholm.

Thanks to the generosity of Professor Menano of the Gulbenkian Institute of Science in Portugal and the Salén Foundation in Sweden, it was possible to hold the symposium at the Gulbenkian Foundation in Lisbon on May 11, 1987, almost exactly 300 years after the public debut of Newton's *Principia*.

WAAS was able to attract a number of eminent scientists and artists as speakers at this symposium, and the speeches covered topics ranging from cosmology to ecology, arts and economics. The organizers believe that the theme, or as it turned out, themes of the symposium will be of great interest to all the Fellows of WAAS. We hope that the material contained in them might initiate debate among the Fellows via the WAAS Newsletter; involving humanists, artists and scientists. We could think of no better forum for a debate on the subject of the shift of paradigm in science and society, and decided therefore that the proceedings of the Lisbon Symposium should be made more widely available, in the form of this publication.

The desire to understand the meaning of his own existence, and the need to rationalize and justify it within some coherent framework, has been and still is one of the most powerful motivating forces of the human being. This profound desire, which has given rise to all the myths and religions of humanity, and to the great philosophical concepts, also lies at the roots of the formulation of scientific method.

But, as Jacques Monod pointed out in his famous book *Chance and Necessity*:

> "While the myths, religions and philosophies did bring positive answers to the problem of meaning, and while it was believed for a long time that Science would bring

the final, definite solution, we now begin to realize, at last, that the problem of meaning is the one to which no scientific answer will ever be provided."

Since man first began inquiring into the meaning of his own existence, the ethics and values resulting from this inquiry have always been based on some essential relationship assumed to exist between him and the universe. We now know that the only authentic relationship is via the abstract, the no-osphere; that man, the stranger in the cosmos, can only conquer the universe through knowledge.

In his paper, cosmologist **Professor Edgard Gunzig** from Professor Prigogine's innovative research team in Brussels points out that we are presently witnessing a new situation in physics in which any improvement in our understanding of the universe leads directly to improvements in our understanding of the fundamental interactions controlling the elementary particle world – and vice-versa. For the first time we have a true interplay between the understanding of the macro-cosmos and the micro-cosmos.

Professor Gunzig calls his paper "Why is there something rather than nothing – for instance, a universe?" He proposes a cosmological history in which the traditional singular Big Bang event is replaced by an instability in an enormous vacuum. This vacuum makes a transiton to a first "inflationary exponential space-time stretch" during which the cosmological constituents are created from the vacuum. After some 10^{-37} seconds the production mechanism stops and this primordial stage shifts over to a stage governed by a more common expansion law which has lasted up to the present stage of the universe, i.e. about 15 billion years. The universe and the vacuum appear therefore as two phases of one and the same subtract. From this very recent theory of the universe, it appears that this universe will have a cyclic history on a gigantic cosmological scale.

The question of how long this primordial vacuum will last before it blows up suddenly is thus invalidated. By this new approach to the time-ordered sequence of events, we are simply the protagonists and observers of <u>one</u> particular cosmological cycle among an <u>infinite</u> sequence of identical cosmological histories!

Professor Paul C. W. Davies, in his paper "The New Physics and World Paradigms", touches on the same basic question as Professor Gunzig: the question of the initial conditions of a physical law: in Professor Davies' paper, Newton's laws of gravity and motion.

Davies points out that, paradoxically, scientists are happy to believe in mathematical statements that describe laws, but until recently they have turned away completely from any statements about ultimate initial conditions, claiming that such conditions lie outside the scope of science.

He refers here to some very recent work by James Hartle and Stephen Hawking in England, who have made the first serious attempt to formulate a "law of initial conditions". The same work is referred to by Professor Gunzig in his paper. Hartle and Hawking solve the problem of cosmic initial conditions by abolishing the origin of the universe altogether! In this system <u>time</u> is still finite and bound in the past, but space-time has no boundary or edge, no event that corresponds to an act of metaphysical creation.

Their approach results, says Davies, in a form of expanding space and matter which is entirely consistent with what is observed by experiments today. Davies believes that however refined the present new science of creation becomes, it will never resurrect the old world view of a clockwork universe. Newton's famous laws do indeed uniquely determine subsequent states of a system once the initial conditions have been given. But there are now many reasons for rejecting this mechanistic Newtonian paradigm.

The existence of the complex systems, physical or biological, which we observe today is <u>not</u> fixed by the initial state of the universe. The particular form of a complex system, according to the new theories, is something that arises purely spontaneously, without any underlying lawful reason. According to this viewpoint, there is nothing inevitable about the existence of living matter: it is merely a fortuitous accident of nature.

These additional laws and principles of nature explain, for the first time, the rather extraordinary innate tendency of matter and energy to undergo 'self-organization'; to leap spontaneously into states of even greater organization and complexity. How nature possesses such amazing creative power has always been a mystery.

All this points towards a post-Newtonian paradigm in which complex organization is recognized as a primary phenomenon and not as an obscure derivative of the physics of elementary particles plus initial conditions fixed æons ago. Professor Davies finishes by stating that the world paradigms of Newton, which served so well to advance physical science for three centuries but inadvertently inculcated an obsession with reductionism, have now run their course.

> "Three hundred years on, Man and Mind are once again emerging as central aspects of Cosmic reality."

Professor Peter M. Allen, another scientist from the Brussels school, presented a paper called "Ecodynamics: Life beyond the Newtonian paradigm", which extends the current theory and concepts to the bio-social world. Professor Allen is the scientist who, probably more than anybody else, has applied Progogine's theory to real world problems.

He begins by pointing out that when the laws of Newtonian physics and thermodynamics were applied to fields such as economics, biology and anthropology, 'understanding' was based on assumptions about 'equilibrium' and the search for the 'appropriate' potential function which governed the evolution of these systems – utility, fitness, efficiency etc.

However, the equilibrium hypothesis remains tenacious, mainly because it avoids all the real difficulties of life, and can lead to elegant theorems and lemmas which are the very stuff of PhDs, professional appointments and honorary degrees. Despite enormous investments in research into economic, ecological and social systems, equilibrium concepts have failed to provide satisfactory models, and our understanding of the evolution we observe remains, essentially, based on 'experience'.

The fundamental reason for this, says Allen, is that the basic paradigm – our whole way of thinking about such things – is wrong. The complex systems which we see around us are neither at nor necessarily on their way to being in equilibrium. All living things have in fact evolved in a state of non-equilibrium! Professor Allen then goes on to give extensive and highly illustrative examples of how non-equilibrium systems become 'creative', generating new structure and complexity. The price we pay for this is a loss of 'predictability'. For example, symmetry-breaking transitions can occur spontaneously so that truly 'new' structures can be created. In this fact lies the real source of innovation in the physical and biological world.

When we turn to human systems, the same principles apply. If all individuals were identical, and had the same 'values', there would be no choice of behavior available. The whole population would 'lock on' to a single behavior pattern, and there would be no information on what it would be like to do anything else. Such a system would not possess any adaptive capacity.

Any simple model constructed in terms of averages, supposing a deterministic link between environment and behavior, misses the essential nature of the evolutionary process. The fundamental point raised in Prfoessor Allen's paper is that discovery and innovation in biological human systems can only be achieved by going 'beyond' the present system. In human systems we need what he calls 'stochasts' who, for whatever reason, do not simply respond to the information which exists about the present returns on effort. However we also need 'cartesians', who are the backbone of the system and its conserving force. The overall success of the system is determined by the balanced co-existence of these two types, and by the manner in which new information is channelled into the system.

Traditionally, science has accepted a description of the internal functioning of an object considered in isolation as the 'explanation' of its behavior. Here, however, we see innovation and change as part of an evolving whole, and the explanation provided by history reflects the inherent unity of the living world. Allen appropriately finishes by saying that 'life begins beyond Newton'.

Extrapolation from Allen's paper leads directly and naturally to the ideas contained in the two socially orientated papers presented in Lisbon: Professor Harlan Cleveland's paper on the "Information Society" and Dr Calestous Juma's paper on "Non-Equilibrium Economics".

Professor Harlan Cleveland begins by stating that in the 300 years since Newton, Science has elbowed aside the Church - all churches, reformed and orthodox - to become a kind of secular religion. It was not, Cleveland says, until Newton had pictured the universe as guided by precise laws of motion tending to harmonize the forces of nature, that John Locke found in 'laws of nature' the foundation for human society; Adam Smith discovered an "invisible hand" to guide trade and industry according to the (natural) law of supply and demand (in equilibrium); and James Madison wrote that a balance among "factions" might, like the counterpoise of heavenly bodies, provide a democracy with built-in self-control.

The Jeffersonian model for a republic, with its reasonable, self-reliant citizens, its orderly and effective institutions and its 'mild' government, was thoroughly Newtonian in spirit and conception. Cleveland eventually arrives at the conclusion that the convergence of two separate lines of already powerful science-and-technology, i.e. faster computers and more reliable broad-band telecommunications, is creating societies where the dominant resource is information, the dominant activity is no longer the production and exchange of things but the production and sharing of symbols.

Information-as-resource (unlike land and other 'natural resources') he says, can expand as it is used, can be transported at the speed of light, and is much harder than tangible resources to hide or hoard. Information cannot be owned. The one thing we cannot do, in the Age of Information, is to keep people ignorant or quiet about things that are going on in the world around them.

Cleveland presents an interesting model for the ethic of ecology as an interlocking system of human self-control, a creative combination of human limits and human opportunities. He concludes by saying that, 300 years after Newton, we have come to a new watershed in the unfolding story of humankind. What we now decide to do to the natural environment may, for the first time in world history, be even more significant than what Nature does to, and for, its human species.

The purpose of science and technology, the unleashing of curiosity and harnessing the human urge to invent and innovate, is to contribute to the fulfillment of basic needs, material and spiritual, of humanity. A new socio-ethical paradigm is emerging.

Calestous Juma from Kenya argues, in his very extensive paper "Non-Equilibrium Economics: Alternative paradigms and technology policy", that part of the failure of social and political policies in Africa must be attributed to the extensive dependence on Newtonian metaphors used in the analysis of its economic and ecological problems. Most of the proposed solutions for Africa, he says, are based on reductionism and static Weberan institutional mechanisms.

What is in fact needed is an analytical framework that recognizes the fact that economies are open systems which evolve and are constantly reorganized through the introduction of new information and technology. A non-mechanistic approach would lead to alternative policies not preoccupied with the restoration of economic equilibirum, but which instead emphasize the accumulation of technological capability, organizational flexibility, social experimentation, recognition of diversity and autonomy. In other words, the same innovative adaptability that Allen spoke of. It is indeed interesting to see how close the arguments of Juma and Allen are. Juma points out that it was Marshall - not Marx - who first argued that economics was like biology, because they both deal with "a matter, of which the inner nature and constitution, as well as the outer form are constantly changing". For Marshall, the subject matter of economics was "human beings who are impelled, for good or evil, to change and progress".

Juma states in his conclusion that the 300 year grip that Newtonian concepts have had on economic thought is beginning to wane. Mainstream economic thought has not yet come to terms with the philosphical and practical implications of non-equilibirum ideas. The reason for this, Juma says, is that economics, in his opinion, is one of the most Newtonian of the social sciences. As in the Prigoginian world, change will involve a long-term process of moving from being to becoming.

Two papers from the Arts were also presented in Lisbon: one by the Swedish architect and artist Professor Hans Nordenström, and the other by art historian Professor Florence Hetzler from the USA.

Professor Nordenström discussed the similarities and differences between the arts and sciences, in particular their relations to ethics and the contemporary human condition. He felt that the relationships between these two sides of human creativity should be strengthened. There is a need, Nordenström claims, to re-create the connection between the useful and the beautiful - a new ethic.

Professor Florence Hetzler concentrates her paper on the influence that Newton's theories and philosophy have had on the arts and literature. She refers, for instance, to Einstein, who once said about Newton:

> "In one person he combined the experimenter, the mechanic and, not least, the artist in expostion. He stands before us strong, certain and alone, his joy in creation and his minute precision are evident in every word and in every figure."

Einstein thus makes Newton not only one who has influenced artists, as he did in his ***Opticks***, but presents Newton also as a literary figure and a writer of literature.

A common denominator of all the papers presented in Lisbon is spontaneous creativity, whether in cosmos or human systems; creativity that results in deviation from the average and innovative adaptability, and creates alternatives to what already exists.

It is ironic, perhaps, that we are now asking for alternatives to that mechanistic world view which is so much attributed to Newton's work, while at the same time we all recognize that Newton represented an enormous creative power far from the 'linear averages' of his time. He was a man of great imagination and creativity, concepts which we find are not different in science from what they are in art.

Dr Forti and myself state in our opening paper that the new vision of the world which is gradually emerging from the work of Heisenberg, Einstein, Popper, Picasso, Salam, Prigogine, and many other scientists and artists, is more stochastic and less deterministic, but it gives back to man a sense of greater freedom, the sense of hazard and adventure. This, in our opinion, is the most important feature of modern science and modern art - it gives back to humankind the ethical and spiritual dimension.

300 Years After Newton — The end of a paradigm?

by

Augusto Forti and Sam Nilsson

The era when Calouste Gulbenkian amassed his fortune and as a great *mecene* established the Gulbenkian Foundation, was an era when we were confident that the earth's resources were infinite and eternal, just like the movements of the planets in the 'perfect' universe of Newtonian theory.

Thirty years later, the Club of Rome[1] made known what geologists had already known for some time: that oil was a finite resource, just like coal or any other natural resource, regardless of the beliefs of many of the economists of the early part of this century.

The challenge of science has always been to formulate a coherent and acceptable picture of the world and the universe in which we live. As Popper says: "In this endeavor, physics, with its blend of speculative creativity and opening to experience, has long been the leading science and tool for understanding the world, before chemistry and biology."

But scientific theories and ideas are alive during the evolution of human thought for a longer, or a shorter, time.

The birth of a paradigm

Three hundred years ago, Newton published *Philosophiae naturalis principia mathematica*. This mathematical masterpiece, which encompassed in a simple formula the movements of the planets, as well as the laws of ballistics, was to influence, even rule, our lives for more than three centuries.

Some historians link the rise of modern science to the disengagement of science from philosophy, but both Descartes and Newton were against this idea. In his day, Newton, like his contemporaries, fought against the supremacy of philosophy and theology over science, but never intended the separation of science and philosophy. The philsophers of the 17th century constructed theoretical defences in order to free scientific research from the power of theological dogma. And just as this philosophical thought was a defence, a guide and even an inspiration for scientific research, so too did scientific research become a guide and inspiration for many enlightened spirits of the time, such as Spinoza, Hobbes and Locke. At that time, there existed a symbiosis between science and philosophy which was closer than it had ever previously been (or probably will be again), and this might explain the strong influence that the ideas arising from this unique period have since had on the development of mankind.

The period was born with the thinking of William of Occam, Duns Scotus, Jean de Joudun and many others, who stated that nature should be explained with its own principles and laws, following from the theory of the "double truth"; vis-a-vis the sacred writings. Similar ideas were expressed by Galileo and Bruno. Inductive methods were given more and more credence, and were used increasingly. This intensive cooperation between science and philosophy reached its apogee with Galileo, when theories and ideas became more clearly formulated, and this paved the way for the establishment of the Newtonian vision of the world.

After Galileo, three ideas were commonly accepted:

1. Nature is filled with facts and behavior which conform rigorously to exact and irrevocable laws. Sometimes the workings of a gigantic mechanism, like the system of the planets, can be deduced from the observation of behavior and laws to which more common objects like a projectile weapon, or a pendulum, are subject;
2. Therefore our minds can comprehend the ultimate truth of natural phenomena;

3. Because mathematics and geometry are the instruments for expressing this truth, they must be the ideal model for thinking. If philosophy wants to be freed from generalizations and uncertainties and to progress successfully like science, it should also adopt such instruments.

Isaac Newton was born in the year of Galileo's death. Newton had an incredible mental capacity and a powerful grasp of mathematical concepts. He invented a new tool known as the differential calculus. Einstein himself said that Newton's intellectual achievements were to be considered the greatest advance in thought that any single individual was ever able to make. Newton produced a synthesis between the empirical inductive method of Bacon and the rational deductive method of Descartes. The result was a splendid mathematical construction that rules many physical phenomena and even today leaves us astonished.

In 1684, Edmund Halley visited Newton at Trinity College to discuss with him the problem of elliptical orbits, which had long puzzled astronomers and mathematicians and seemed to contradict Kepler's third law. Newton, who had solved this problem two years earlier told Halley that is was mathematically possible to solve it, but that unfortunately he had lost his notes. Halley persisted, and Newton started to work on this research again, night and day; so hard that his mind paid a high price. But he succeeded in building a universe ruled by mathematical laws.

For Newton, space was the three-dimensional space of classical Euclidian geometry. It was an empty container, independent of the physical phenomena occurring inside it. Absolute truth and mathematical time flow uniformly of themselves, without regard to any external influence.

Apart from a nervous breakdown, Newton's work resulted in a beautiful vision of the universe which linked the movements of planets and comets, the earth and the moon, the tides of the oceans etc, to advanced mathematics and a simple formula. Through this theory, it was also possible to calculate the mass of the sun and the planets. Newton used to say that he felt like a boy finding a white stone or nice shell on a beach from time to time, on the shore of the vast ocean of truth which has no limits.

In 1686 he presented the complete manuscript of his masterpiece, *Philosophiae naturalis principia mathematica.*, at the Royal Society. Difficulties arose regarding its publication, and it is again thanks to Halley that it was published in 1687, in *Acta Eruditorum* in Leipzig. The review was written by Newton himself, since few of his contemporaries would have been able to understand his work. Newton was probably the only one then able to talk about Newton.

As we know, Newton's theories have influenced subsequent thinking in science, philosophy, economics and practically all other fields of human endeavor. They were soon taught at Oxford and Cambridge, but it was 50 years before Newton's theories were taught at the Sorbonne in France.

The Newtonian mechanistic view of nature became widely accepted and clearly related to a rigorous determinism: the giant cosmic machine was completely causal and predictable. With the firm implantation of the mechanistic world view in the 18th century, physics became the basis for all the sciences. Descartes wrote that "all philosophy is like a tree: the roots are metaphysics, the trunk is physics and the branches are all the other sciences."

Science also made it more difficult to believe in God, leaving a spiritual vacuum which became one of the hallmarks, and anomalies, of our culture. Newtonian theories and the belief in the rational and mechanistic approach to solving all human problems spread rapidly among the 18th-century middle classes: *Le Siecle des Lumieres.* The extraordinary influence of the Newtonian paradigm can be illustrated by the words of one of the foremeost scientists of the 19th century, Hermann von Helmholtz. He was primarily a physiologist, but he said: "To me no theory has the status of a scientific theory, unless it can be formulated in terms of Newtonian mechanics."

Newton became the new Moses. Alexander Pope proposed his famous epitaph for Isaac Newton when he died in 1727:

"Nature and Nature's laws lay hid in night.
God said, 'Let Newton be,' and all was light."

So in 18th-century England, Newton was the new Moses who had been shown the "Tablets of the Law". The Greek hubris!

In the Newtonian universe, romantic philosophers discovered an enchanted world animated by 'natural' (Newtonian) forces. For positivists, it meant the success of a methodology, a recipe identifiable with the very definition of science. The difference in the perception of nature and the universe can be illustrated by the views of Emanuel Kant (1724-1804) and Johann Wolfgang von Goethe (1749-1832).

When Kant began to trace the boundaries between mathematics and metaphysics (mathematics, which is privileged to proceed with a deductive method from concepts of its own creation, and metaphysics which was privileged to do the same), he observed that the procedures and methodology of philosophers and thinkers in the field of metaphysics were close to those of scientists. The true method of metaphysics, he explained, is identical to the one Newton produced in science and which has proven to be so productive. Like Newton, the philosopher has to search through establishable experiences to find the rules that govern natural phenomena. The complex phenomena of nature will be explained when we are able to formulate these rules and to demonstrate how these phenomena are embodied in them, even implied by them. Kant is therefore the emblematic example of a series of thinkers who proceeded 'enfranchised' by the illumination supplied by Newton.

Goethe, on the other hand, took the metaphysical point of view that nature lay in the depth of the mysterious unknown created by God, and that this was not something that could be rendered ordered and unified by *any* knowledge mankind could possess. So while Kant believed that with man's advances in knowledge nature would eventually be explained entirely, Goethe took the more modest view that nature is filled with God and that man had "investigated all that can be investigated and should humbly respect those things that cannot be investigated."

Kant's views are thus close to the modern scientific paradigms following Newton's, and Goethe's views are closer to those which are growing today in society in general, most notably among creationists and certain religious fundamentalists.

A values crisis

As we approach the 21st century, the evidence of a deep crisis in values is becoming more and more evident. One side of this crisis is the gradual destruction of nature, another is the collapse of social order, particularly visible in countries which we call developing and which are trying to adopt mechanistic (Western) principles and methods (rationalism and industrialization) for their development.

Despite some differences in their thinking, Thomas Hobbes (1588-1679), John Locke (1632-1704) and Jean-Jacques Rousseau (1712-1788) firmly established the social contract theory as an unshakeable foundation for the social framework. Their analysis fitted so perfectly with academic Newtonian techniques used in the natural sciences of their times that it left little scope for doubt that there was a common philosophical framework linking natural sciences and social sciences and that the methodologies used in natural sciences could therefore well be used in the field of the social sciences.

It may well be, however, that the fundamental cause of the two crises we referred to above lies precisely here: that we attempt to analyze and solve society's problems with the linear mechanistic thinking and methods which have been so successful in bringing Western society to its present level of material well-being.

Dennis Gabor (1900-1979), Nobel Laureate in physics (1970), once said: "The so-called Western civilization is based on an extraordinarily successful science and technology, but *spiritually on practically nothing.*" Shigeo Kurebayashi, Director of the International Economic Research Center in Tokyo, has given four principles on which modern (mechanistic) Western society is founded:

i. rationalism
ii. liberalism
iii. individualism
iv. utilitarianism

The principle on which all others are founded, he says, is rationalism, By helping man to overcome superstition, and by liberating the human spirit from the oppression of the Church and the landlords of the Middle Ages, rationalism brought about liberalism as a natural consequence. Since liberalism regards the free will and actions of the individual with respect (John Stuart Mill), individualism took root in the same way. A set of standards with which to evaluate the effect produced by rationalism was needed, and so utilitarianism emerged as its sole system of values.

Having concluded that rationalism is the fundamental principle holding the others together, it becomes clear that while rationalism frees the soul from spiritual and material oppression, it also places man in the highest position in nature, making him free to exploit, in his own supreme interests, all other species. Darwin, Mendel, Marx and Adam Smith are consequential to this type of thinking.

The industrial revolution

The social contract theory came into being within the framework of rationalist thought. Rational and "scientific" in its methodology, it analyzes society and assumes that the smallest unit of society is the individual (reductionism) and that the relationships between society and the individual are contractual. In fact, a very few thinkers during a short period of time shaped the mechanistic world view of the Industrial Revolution that started the exo-somatic machine revolution.

The philosophy of René Descartes (1596-1650), not to mention that of Francis Bacon, is based on the existence of man's "self" as supreme truth. *Cogito, ergo sum* — I think, therefore I am. Descartes stated that the key to understanding the world, to controlling it for human purposes, was to be found in one word: mathematics. The Greek view of history as unfolding chaos and decay was deemed unmathematical and therefore false. Newton's theory became the ultimate proof of this view.

John Locke brought the workings of government and society into line with the new world paradigm, and Adam Smith (1723-1790), as well as Marx, did the same for economics. "The negation of nature," said Locke, "is the way towards happiness." Smith, like Locke, believed that the basis of all human activity is material self-interest. Classical economists after Smith based their ideas squarely on the philosophical framework of the times, namely rationalism and individualism. It was believed that private profits would contribute to the public interest, and other values were discarded as irrelevant. *Laissez-faire* became the order of the day.

Economic theories are all equilibrium theories, which of course derive from natural sciences, and equilibrium and balance would automatically be achieved by the market principle (the "invisible hand"). The explosive development of the natural sciences during the past two hundred years is first of all due to its practical applications. Science has become more integrated with technology and less preoccupied with the understanding of nature and our existence.

As technology led to a feeling of power, we were led to believe that man is now much less at the mercy of nature than he was earlier in history. But we have to realize that the power generated by technology is collective, not individual. And that in contrast to religion, technology is ethically indifferent. Man can do wonders with technology, but he knows no rules or limits for these 'wonders'. We have accumulated an unbounded confidence in technology and lost the sense of our own limits.

In the mass-production and mass-consumption assembly line society, humans are also looked upon as "raw materials" for labor or information. We focus all our interest on the efficiency of the process: the goal is of secondary importance.

We badly need a new philosophy of science, a new vision of the role of science and technology in our society.

Ethics and material consumption

After Adam Smith, classical economists, Marx included, based their ideas on the philosophical framework of the times: rationalism and the mechanistic view of the world. The view of Smith himself was that man must retain "sympathy" as his principle of behavior; a *laissez-faire* economy would thus not obstruct the welfare of society. But history has proven otherwise. '*Homo economis* ' is rather values-free, and bases his decisions on narrow and selfish motives.

In contrast to Smith's microeconomics, macroeconomics took the stance that the study of economics should begin by observing the aggregate sum of the national economy. It was claimed that <u>equilibrium</u> could not be attained by the mechanisms of an entirely free market, that some sort of economic policy was necessary.

One might say that such an argument is totalitarian, since it seeks the value of economic activity in the composite or national economy, and not in the individual. Keynes (1883-1946) points this out in his book *The End of Freedom*, which became the foundation stone of Keynesian economics.

The Keynesian revolution may be compared with the Copernican revolution, since it became a turning point in the paradigm of economics. Keynes believed that economics must be a study of the ethics of rational economy, and his principal objective was full employment.

After the Second World War, concepts of government and economics underwent further changes. It was now considered to be the state's duty to provide citizens with a certain minimum standard of living and to provide social security for the disadvantaged. At the same time, the state became responsible for maintaining a certain standard in industrial activities in order to prevent economic depression. These post-war modifications initiated the creation of the <u>welfare state</u> and the expansion of the public sector.

For about two decades, this post-Keynesian policy worked remarkably well, but we all know that the welfare state, with its growing bureaucracies and huge public sector, is now under serious attack. It seems that Keynes no longer functions at the national level, nor do Marxist theories, both somehow progeny of Isaac Newton. We see clear signs of reverting to Smith's *laissez-faire* economy, in which the Darwinian "survival of the fittest" is a leitmotiv.

We believe that Western societies in particular are gradually coming back to a strictly mechanistic and reductionist paradigm. The social contract theory following the analytical methods of the natural sciences is again breaking down society into its smallest unit: the individual. And we are facing a serious crisis in values at both the national and global levels. This is the same crisis that science went through 50 years ago. But the new concept of science and the new scientific paradigm which emerged from this crisis have not yet been absorbed into and mastered by society in its social, economic and political behavior. As mentioned earlier, it took 50 years before the Newton theories were taught at the Sorbonne in Paris.

The efforts of Prigogine and many others to create a bridge between the new vision of the world being shaped by science and the old vision still held by our decision-makers may well still manage to re-direct the healthy inertia of human society. The new vision of the world which is emerging from the work of Heisenberg, Einstein, Picasso, Popper, Prigogine, Salam and many others is more stochastic, less deterministic, more "uncertain" surely, but it gives back to man a sense of more freedom, the sense of hazard and adventure, and this, in our opinion, is the most important feature of modern science and modern art. It gives back to man his ethical and spiritual dimension.

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Why is there something rather than nothing - For instance, A Universe?

by

Edgard Gunzig

One of the outstanding features of the physical sciences at present is the very recent shift of the old question "Why is there something rather than nothing?" from the area of metaphysics to the rational framework of scientific investigation. This represents a beautiful example of the marriage between two *a priori* distinct facets of reality as described in contemporary physics: Einstein's general theory of relativity on the one hand, which unveils the nature of gravitation; and the quantum theory on the other hand, which provides a description of the microscopic world at the level of the elementary constituents of matter.

In fact, we are presently witnessing a fascinating new situation in physics wherein any improvement in our perception of the universe leads directly to wholesale returns in our understanding of the fundamental interactions controlling the elementary particle world, and vice-versa.

This represents an alternative to the old dream of the unification of all types of interactions in nature as different facets of a single unique proto-force. This unification seems now to be true for all interactions with the exception of gravitation, which for several decades resisted inclusion into such a unified description. At present, we are witnessing a subtle feedback interplay between the unified quantum laws controlling the microscopic world, and the singular, deviating, classical gravitational interaction. This phenomenon has its origins in a very specific and unique property of the gravitational interaction: its universality. This property is probably one of the most fundamental in nature. The absence of just this property would undoubtedly have prevented the emergence of a universe, or at least drastically altered its cosmological landscape.

What is the significance of this universality? Only one type of gravitational interaction exists: that of attraction. In other interactions two opposites co-exist: attraction and repulsion. A direct corollary of this state of affairs is the absence of gravitationally neutral aggregates: nothing is gravitationally insensitive, everything gravitates; no form of matter-energy is able to escape gravitational interaction. Even the gravitational force itself gravitates! It is this unique property which makes the gravitational interaction so very specific. Although by far the weakest interaction in nature, it is the dominant one with regard to large amounts of energy-matter distributed over huge regions of space. This interaction therefore plays a dominant role with respect to the structure and evolution of the universe. My purpose here is to emphasize that universal gravitation not only directs and drives our cosmological history, but was responsible for the genesis of the universe itself! Indeed, an unavoidable fallout of the universality of the gravitational interaction is its influence on the microscopic world, and hence also on the "quantum vacuum".

What is the quantum vacuum? In classical physics, a vacuum is just the absence of anything. But a corollary of the contemporary view of the structure of the microscopic world, quantum physics, is that a vacuum is the seat of a turbulent and incessant activity. In fact, the quantum vacuum constitutes what is left when everything possible has been erased. What remains is the world of "virtual particles". According to the quantum rules controlling the microscopic world, an unavoidable uncertainty exists as to the energy (hence the mass) of any system, in relation to the time of its existence: the shorter its lifetime, the greater the uncertainty about its mass (energy).

A direct consequence of this fundamental property is the existence of a strange "zoo" of would-be particles, emerging anywhere spontaneously from the vacuum in pairs, whose fate is to promptly annihilate each other, leaving nothing behind. They exist the time of an uncertainty - they are not real particles in the sense that they are not able to propogate freely, and therefore do not allow direct experimental detection. But their existence "polarizes" the vacuum, thereby inducing a series of observable phenomena.

A principal question concerns the possible actualization of these potential entities: can we provide conditions which make the annihilations of the virtual particles impossible, transforming them into real particles which are able to participate in the usual atomic structures? One appropriate technique adapted to this purpose exists: it is to provide these virtual pairs with a definite amount of energy, the amount corresponding to their mass. This process occurs perpetually in the vicinity of atomic nuclei, where the virtual pairs extract the required energy from the electrical field in these regions. The virtual particles are subjected, like any other forms of matter-energy, to universal gravitational interaction. Could it be possible to conceive an actualization of virtual particles by an appropriate energy extraction from gravitation?

The answer is quite unexpected. It appears indeed that there is a peculiar gravitational mode, linked with the large-scale space-time curvature, which carries an energy opposite to the conventional positive matter-energy, i.e. negative energy! In other words, an intrinsic internal negative energy reservoir exists unbounded from below - the large-scale geometry itself - from which the matter-gravitational system may extract any amount of positive energy. In an initial quantum vacuum this may then be transferred to virtual particles, converting them into real ones. Stated in another manner, real particles carrying positive energy are created at the expense of appropriately curving the initial flat quantum vacuum space-time, and vice-versa: the more particles are created, the more space-time is curved. The positive energy carried by the former is perpetually and exactly compensated by the negative energy associated with the latter, maintaining the total energy at its zero initial vacuum value. Such a process and the corresponding cosmological history will be hereafter denoted as Self-Consistent (S.C.).

Although permissable in principle, is such a mechanism plausible and is it realized? In other words, is there some profound reason for the initial vaccum to transit to a S.C. cosmology, rather than keeping its virtual population? The answer to this question is also quite unexpected: the quantum vacuum is unstable in the unavoidable presence of gravitational interaction! Moreover, this instability forces the vacuum to blow up! It then transits to a unique realization of a S.C. cosmology: the "inflationary universe", wherein any space-time volume becomes inflated exponentially with the elapse of time. A perpetual production of particles insures that the energy density of this universe remains constant during this inflationary cosmological regime.

We are, of course, not living at present in such a rapidly expanding universe. A motivation has to be found for the end of the inflationary cosmological regime and the onset of the expansion as observed at present. The phenomenon is the following: the nature of the generic vacuum instability, as well as the resulting S.C. cosmological stage, imply that the primordially created cosmological constituents are mini black holes, characterized by a mass approximately equal to 50 times the Planck mass m_p ($m_p = 10^{-6}$ grams).

It is known from the work of S. Hawking that black holes are not really black, as they emit particles as well as radiation: they evaporate. It is precisely this evaporation time which marks the end of the inflationary stage and the onset of the expansion stage, as observed at present. This evaporation time, corresponding to the mass of the S.C.-created mini black holes, is approximately equal to 10^{-37} seconds. Hence this primordial regime lasts only a very short time: 10^{-37} seconds! The following regime extends from that time on up until the present epoch, i.e. around 15 billion years.

The important fact is that the connection between both regimes imposes severe constraints on the cosmological properties observed at present: the latter are indeed placed in relation to the instability phenomenon as well as the properties of the inflationary stage.

These are dependent on the value of three fundamental constants in nature only: the speed of light, the characteristic constant controlling the quantum laws and the gravitational constant appearing in Newton's (or Einstein's) gravitational law. The connection between the two evolutionary cosmological regimes imposes the condition that the present observed data be equally dependent on these fundamental constants only. Moreover, their explicit dependence is fixed by this cosmological history.

The power of a theory depends not only on its internal consistency, but on its predictive value as well. And the S.C. cosmology presented here fulfills both of these requirements: apart from its internal consistency, its quantitative predictions are characterized by an unexpected agreement with the specific cosmological data obtained from observations at present.

In conclusion, we propose a cosmological history in which the traditional singular Big Bang event is replaced by an instability in the vacuum. This instability is unable to sustain the presence of sufficiently energetic virtual particles subject to the universal effect of the gravitational interaction. The vacuum then transits to a first inflationary exponential space-time stretch during which the cosmological constituents are created from the vacuum. After some 10^{-37} seconds, the production mechanism stops and this primordial stage shifts to a usual expansion law which lasts up to the present epoch.

We saw that the total energy of the matter-gravitational system in this S.C. scheme keeps its initial zero vacuum energy. The universe and the vacuum appear therefore as two phases of one and the same subject!

As the universe expands, the "cosmological fluid" becomes more and more dilute, tending towards a configuration reminiscent of the vacuum. A new instability phenomenon will then occur beyond a certain dilution, hence in a given future. We are now calculating the "gestation period" of our old universe, before it is rejuvenated. From that point of view, it appears that this universe will undergo a cyclical history on a huge cosmological scale.

Hence the question "How long does the primordial vacuum last before suddenly blowing up?" is eradicated by this new avenue of approach to the time-ordered sequence of events. From the point of view of the present theoretical approach, we are just the protagonists and observers of one particular cosmological cycle in an infinite sequence of identical cosmological histories!

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The New Physics and World Paradigms

by

Paul Davies

To most people it is obvious that the cosmos is an organized unity. Everywhere we look, from the deepest recesses of the atom to the most far-flung galaxies , we encounter order. The diverse systems of nature, their richness and complexity notwithstanding, co-exist in harmony. Furthermore, complexity — in all its forms — co-exists with the astonishing simplicity of the underlying laws of physics, so that the world is at once both simple and complex.

We celebrate here 300 years of Newtonian influence on scientific and non-scientific thought. Newton's greatest contribution was to demonstrate that the systematic imaging of the world in simple mathematical statements could lead to accurate predictions — predictions of the positions of the planets, the paths of projectiles and, ultimately, the motions of individual atoms. His laws of motions encapsulated the fact that material bodies do not move in a random or haphazard way, but according to strict mathematical rules. In our modern way of speaking, we say that matter moves according to certain differential equations.

I would like to address a particular aspect of Newton's mathematical laws, an aspect that carries through to all other fundamental laws of physics, and is a central part of the Newtonian paradigm. I refer to the questions of *initial conditions*. The issue goes to the very heart of what we mean by law. The whole idea of a law is that it expresses a regularity of nature, and a regularity is something that recurs again and again in similar systems.

Let me give an example. It is a consequence of Newton's laws of gravity and motion that all balls thrown in the air follow a parabolic path. They do not, however, all follow the *same* path. Some parabolas are low and gently curving, others are high and arching. The point about a law of nature is that it *constrains* the behavior of a physical system without uniquely determining it. If there existed laws that uniquely fixed how projectiles move, games such as football and cricket would be pretty dull.

Although Newton's laws fix the general shape of the path, then, the *specific* parabolic shape is determined by something in addition to the laws, namely, the initial conditions. In this case the initial conditions are the speed and angle of projection. According to Newton's laws, once these conditions are specified, the path of the ball is *uniquely determined*. There is no longer *any* freedom left. This is a mathematical fact which can be rigorously proved. And what is true for the ball is true of planets and atoms. Indeed, it is true for every material body in the universe, and hence for the universe as a whole.

This world view of the 'clockwork universe' reached its most extreme form with a famous statement by Pierre Laplace:

> Consider an intelligence which, at any instant, could have a knowledge of all forces controlling nature, together with the momentary conditions of the the entities of which nature consists. If this intelligence were powerful enough to submit all this data to analysis it would be able to embrace in a single formula the movements of the largest bodies in the universe and those of the lightest atom; for it nothing would be uncertain; the future and the past would be equally present to its eyes.

Laplace's statement implies that everything that has ever happened in the universe, everything that is happening now and everything that ever will happen, including all the actions of human beings, and right down to the tiniest wobble of every atom, is already fixed and unalterable; indeed, has been laid down since the beginning of time. The universe is thus reduced to a machine, slavishly implementing a set of instructions built into it at the beginning in the form of its initial conditions.

What of those initial conditions? I have already noted that the motion of a ball is determined uniquely be its initial conditions. But what determines those conditions? If the system that projects the ball is also subject to deterministic laws, then the initial conditions of projection of the ball are in turn fixed by the initial conditions of the projector, which in turn are fixed by the some larger system and so on. Eventually our considerations encompass the entire cosmos, and we are forced to ask about the initial conditions for the universe as a whole.

Throughout most of the history of science, scientists have generally ducked the issue of initial cosmic conditions. Either they have regarded the subject as more properly lying in the province of theology than physics, or they have assumed an eternal universe, i.e. a universe which had no origin in time, but which has existed for ever in one form or another. Newton, however, realized that there is a problem here concerning gravitation. According to his theory of universal gravitation, published in the Principia, gravity is always an attractive force which pulls all matter towards all other matter. Every star, every galaxy, pulls on all its neighbors. Why then, asked Newton, did not the whole assemblage of stars all fall together in one great mass?

Newton had a clever idea to rescue the universe from gravitational collapse. He argued that if the universe were infinite in spatial extent, and uniformly populated, on average, with stars, then the average pull of gravity on a given body would be the same in every direction. The forces would therefore tend to cancel each other out. There would be no privileged center towards which the body would be pulled. In this way, the universe could apparently endure for ever without falling in on itself. If that were the case, the question of initial conditions could then be sidestepped, because there was no actual beginning — no 'ultimate initial state'. The initial conditions could be pushed further and further back in time, back to infinity.

Modern cosmology came face to face with the same issue when Einstein replaced Newton's theory of gravitation with his general theory of relativity in 1915. Again, gravitational attraction threatened the universe with collapse. Einstein sought to prop it up by introducing a remarkable new feature — antigravity. He suggested that the force of attraction between the stars could be balanced out with a universal repulsive force, a force what grows larger with distance. While negligible on the scale of the solar system, this antigravity would accumulate over the cosmos and counteract the gravitation of all the stars.

Unfortunately for Einstein, the idea was a failure. The cosmic balancing act turned out to be unstable. Whether or not antigravity exists, the universe cannot remain static: it has either to collapse or expand. Then, in the 1920s came Edwin Hubble's epoch-making discovery. The universe is not, after all, static. It is, in fact, expanding with every cluster of galaxies moving away from every other in a remarkably uniform manner.

The expanding universe led immediately to a very profound conclusion, Playing the great cosmic movies backwards in time, the galaxies must have been closer together in the past. A simple calculation shows that there must have been a moment when all the matter in the universe was squashed together into a very dense state. In this dense state, the gravitational forces were immense, and to have escaped from this state the universe had to have been expanding explosively fast. Thus the universe had its origin, it seems, in a gigantic explosion, popularly known as the Big Bang.

Most cosmologists now accept that the universe began with a Big Bang, which occurred about 15 billion years ago. Good confirmation of this theory comes in the form of a uniform background of heat radiation that bathes the entire cosmos. This radiation is believed to be the fading glow of the primeval heat that accompanied the birth of the cosmos. It has travelled to us across space almost undisturbed since shortly after the initial furnace cooled.

There is a common misconception that the Big Bang was the explosion of a lump of something in a pre-existing void. This is not correct. According to Einstein's general theory of relativity, space and time are ultimately coupled to matter. The extreme compression of matter represented by the Big Bang implies something equally violent happening to space and time. Indeed, cosmologists believe that the Big Bang was the *origin* not only of matter, but of space and time as well. That is, space and time came into existence with the Big Bang. There was no 'before'. This echoes the words of St Augustine, who said that the world was made with time and not in time.

If there really was an origin of time, then the question of the cosmic initial conditions must be faced squarely. One can ask, why was there a Big Bang? Why did it have the energy it did? Where did all the matter and heat come from? Why did they emerge expanding in the way that we see them?

When one comes to look at this more closely it turns out that there are many very remarkable features about the initial conditions. First, on a large scale (i.e. greater than the size of a cluster of galaxies)' matter and radiation are distributed with extraordinary evenness throughout the cosmos. The strength of the background radiation left over from the Big Bang, for example, is the same in all directions to one part in ten thousand.

On the other hand, the universe is not precisely smooth, Locally, there are small departures from regularity that are manifest as galaxies and, on a smaller scale, as stars. It is this local irregularity that gives rise to planets and, ultimately, life. Without it we would not be here to wonder about these things. Yet the local irregularity is also rather precise and uniform. Had it been greater in degree, most of the universe would have ended up in the form of black holes. With less local irregularity, the primeval gases would never have aggregated into galaxies and stars. The cosmos, then, is therefore in a rather odd state of almost but not quite perfect order — large scale regularity combined with small scale irregularity of a precise degree.

Another surprise concerns the *rate* at which the universe expands. Had the Big Bang been bigger, all the material would have dispersed by now and no galaxies would have been formed. On the other hand, if the explosion had been less vigorous, the whole assemblage of galaxies would have collapsed back on itself long ago, in a cosmic spectacular, known 'in the trade' as "the Big Crunch". Evidently the explosive vigor of the Big Bang has been matched to the gravitating power of the cosmos almost precisely, so that the universe expands at a rate that puts it exactly on the dividing line between these unpalatable alternatives. To achieve this balancing act the bigness of the Bang had to be fine-tuned to about one part in 10^{60}!

Not only was the Big Bang exceedingly felicitous in its vigor, it was also uncannily well-orchestrated in its synchronization. Each region of the universe went bang! at precisely the same time and with equal strength in every direction, to give a highly regular, coherent, outward motion. And this happened in spite of the existence of so-called horizons in space.

Horizons occur because light travels at a finite speed. At any given moment, therefore, there will be regions of the universe that have not yet 'seen' each other, because light will not have had time to travel between them since the origin of the universe. Now physicists are convinced that no object or physical influence can travel faster than light. This means that regions of space that cannot 'see' each other cannot exert any physical influence on each other by any means. They are completely causally disconnected. It is then a great mystery as to why these apparently casually unrelated regions should nevertheless look and behave with remarkable similarity. Indeed, by looking on opposite sides of the sky, we can see different cosmic regions that have apparently never been in communication or causal contact since the beginning of time, yet these regions look more or less

In the early days of the Big Bang theory, these extraordinary features were simply assumed. That is, the universe was assumed to have started with certain very special initial conditions, the reason for which lay beyond the scope of science. Today, the New Physics has revolutionized our thinking on this subject, and opened up the prospect of being able to explain the initial conditions of the universe in the same way as one explains its subsequent motion.

Before getting into the details of this, let me discuss the underlying philosophy. When a physicist claims to have 'explained' a natural phenomenon, such as the motion of the moon, using a Newtonian example, he means that he is able to write down a law of physics in the form of a mathematical statement, and that, given the initial conditions of the problem which have to be found empirically, then the system obeys that mathematical statement, at least to a certain level of approximation. The physicist cannot say *why* the system conformed to that law; he cannot say why the law works. It simply does, as an observational fact. For some reason the world possesses systematic regularities that we call laws, and that is simply a brute fact.

When it comes to initial conditions however, the situation is a bit different. We can indeed ask why the ball was thrown at the speed and angle it was. The answer may be 'because the thrower wanted to hit the wicket' (for those who understand Britain's 'absurd' national sport). One could even ask why the moon had the particular initial conditions it did, i.e. why it was in such and such a position on such and such a day. You would be hard pressed to find the answer, because it depends on the details of the formation of the solar system, about which we know little, but the question is not meaningless and could be answered in principle.

All ordinary initial conditions are of this sort. One can in principle answer the question of why just *those* conditions, by appealing to a wider system. There is only one exception: the ultimate initial conditions for the universe as a whole. In this particular case, because we are dealing with the whole of the physical world, there is no wider system that can be used to explain those conditions, unless one appeals to a deity outside the physical universe.

So the ultimate cosmic initial conditions have the same status, then, as the *laws* of physics. They cannot be explained within the context of science. Yet paradoxically scientists are happy to believe in mathematical statements that describe laws, but until recently have they turned away completely from any mathematical statements about ultimate initial conditions, claiming that such conditions lie outside the scope of science. But I argue that this is misconceived. Why should physicists not propose mathematical statements, or 'laws', about the cosmic initial conditions in the same way that they propose mathematical statements about the ordinary ongoing laws of physics?

One anxiety might be this: how can we test such a 'law of initial conditions'? We can't go back to the Big Bang and see what the conditions were. However, the form of the universe today carries an imprint of the initial conditions. In principle at least, we can work backwards from the present structure and motion of the cosmos and deduce the initial conditions that led to the present state. We can look at such things as the smoothness of matter and heat radiation, the rate of expansion an so on, and try to calculate what initial states could produce this present state. Thus, at least *in principle*, laws of initial conditions can be judged empirically, just as ordinary laws are.

As far as I know, it is only very recently, and most notably with the work of James Hartle and Stephen Hawking, that any serious attempt has been made to write down a 'law of initial conditions'. Their work is formulated in the context of the new Big Bang theory, which recognizes that the very early universe was dominated by quantum effects. Quantum physics is normally associated with microscopic systems only such as atoms, but in the first fraction of a second quantum physics dominated the behavior of the universe as a whole.

Quantum physics can lead to many weird effects, but one of the strangest is that it can turn time into space under some circumstances. Hawking and others have found that when the universe was sufficiently small in size, time behaved like a fourth dimension of space. The question then arises as to the geometry and topology of this four-dimensional space. The choice of this geometry and topology amounts to a statement about the cosmic initial conditions, although the word 'initial' here is not longer appropriate because we are no longer talking about time, but space.

Hartle and Hawking choose as their statement about the initial quantum state of the universe a mathematical ansatz that is in many ways very natural because it suggests that the universe began, in some sense, in the lowest energy state. In other words, it is a minimalist assumption. Translated into the geometry and topology of the four-dimensional space mentioned above, the Hartle-Hawking ansatz amounts to supposing that the four-dimensional space is shaped rather like a hemisphere. The 'south pole' of the hemisphere is what we previously thought of as the Big Bang, the beginning of time. In fact, it is just a point in four-dimensional space like any other in its vicinity. That is, it does not enjoy special status. The universe does not begin or end there any more than the Earth begins or end at the south pole, even though from a map using Mercator's projection one might have been forgiven for believing so.

Thus, Hartle and Hawking solve the problem of cosmic initial conditions by abolishing the origin of the universe altogether! In this system, time is still finite and bounded in the past, but space-time has no boundary or edge, no event that corresponds to an act of metaphysical creation. Furthermore, the form of the expanding space and matter that emerges from their ansatz is entirely consistent with what is observed. True, the ansatz does not make any very strong statements about the world — it does not tell you how many stars an average galaxy will have for example. Rather, it tells us only about the overall general smoothness in the distribution of matter and energy. But it could have led to nonsense, predicting a world in which the universe expanded in one direction and contracted in another, for example.

The Hartle-Hawking ansatz is the first attempt (as far as I know) to bring the cosmic initial conditions within the compass of science. One might well ask whether a much more refined ansatz would explain the form of the universe at a much greater level of detail. It is conceivable, for instance, that an all-embracing elegant statement about the quantum state of the early universe, to be placed alongside similar elegant all-embracing statements about the lawlike regularities of the universe — would contain within it an explanation for the initial conditions of the moon? Or the Earth? Or oneself? In other words, is it conceivable that we will return to the world view of Laplace's demon, but with an explanation of *how* the universe achieved the state that it has?

One of the deepest mysteries of nature is that a world which is governed by astonishing simple underlying laws nevertheless displays extraordinary complexity. Are we to suppose that the existence of highly complex systems such as the human brain owes its explanation ultimately to a simple mathematical form of the initial quantum state of the universe as a whole? Is mind built into the Hartle-Hawking ansatz, or something like it?

I believe that however refined the new science of creation becomes, it will never resurrect the old world view of the 'clockwork universe'. The reason for this is simple. Even if we can find an ansatz to specify a highly plausible initial quantum state for the universe, and even if that state is unique, then it is not in itself sufficient to explain everything that subsequently happens in the universe. It cannot alone explain, for example, the existence of the human brain. The reason for this is that the concept of determinism on which the Laplacian idea rests is now utterly discredited.

Let me remind you that Newton's famous laws do indeed determine subsequent states once the initial conditions have been given. But there are now many reasons for rejecting this Newtonian paradigm. Some of these reasons are related to the work already described by Prigogine and Gunzig. That many physical systems are so exquisitely sensitive to their initial conditions that only if these conditions are fixed with infinite precision can their behavior be said to be determined. Yet infinite precision is an idealization that fails in the real universe. I have mentioned that the Hartle-Hawking ansatz refers to a *quantum* description of the world. It is a fundamental feature of quantum physics that the world is inherently indeterminate and unpredictable. Specifying the quantum state only suffices to give the relative probabilities that certain things will occur. No doubt in principle one could use the Hartle-Hawking ansatz to compute the probability of, say, an Earth-like planet forming in a particular galaxy, but the quantum state specified by their ansatz does not *compel* the universe to produce such a planet.

In addition to the fact that quantum effects introduce an inherent and irreducible uncertainty into all physical variables, there is also an inherent limitation in the information processing capacity of the cosmos. In other words, even if one had the *exact* initial conditions for a system, and commandeered the entire universe as a computer to work out the subsequent behavior, it would still be the case that for certain familiar unstable systems (such as the conical pendulum) the cosmic computer would be unable to maintain the level of precision necessary to accurately predict the motion for very long.

If I am correct about this, and the existence of the complex systems we observe today is not fixed by the initial state of the universe, then how are we to explain those complex systems? What view are we to take of the existence of, say, living organisms or intelligent life — or even more modest, yet still unpredictable, systems such as hurricanes?

One point of view is to regard such systems as without explanation. That is, to claim that the particular forms of a complex system is something which arises purely spontaneously, without any underlying lawful reason. According to this viewpoint, there is nothing inevitable about the existence of living matter, it is merely a fortuitous accident of nature. Similar remarks can be made about intelligence. This seems to be the fashionable position among biologists today.

I dislike this position, because it is unscientific. It simply brushes the problem of the existence of complex systems aside, claiming essentially that their existence can never be explained. I strongly believe that the existence of complexity in nature, far from being fortuitous, is inevitable, not because the initial state of the universe is already programmed for complexity, but for an altogether different reason. It is my conjecture that there are lawful regularities of nature that generate complexity. In other words, I maintain that alongside the underlying laws of physics that refer to the individual components of physical systems there are other laws and principles that refer to the collective behavior and organization of large assemblies of components. These additional laws and principles explain the rather extraordinary innate tendency for matter and energy to undergo 'self-organization' — to leap spontaneously into states of ever greater organization and complexity. It has always been a mystery as to how nature possesses such amazing creative power. How is it that apparently blind and purposeless forces, acting together in a random and uncontrolled way, can nevertheless conspire to produce the awesome richness and organized complexity of the natural world — the complexity and order of a snowflake, or a flower, or a brain? What is the origin of this astonishing creative power?

I must emphasize that these new 'organizing principles' to which I refer can be entirely consistent with the known laws of physics. The organizing principles *complement* those laws. There is room for such complementary laws as well as the underlying laws of physics precisely because the universe is non-deterministic. I do not therefore, suggest anything vitalistic here. I reject the idea of mysterious occult forces shaping matter in defiance of the laws of physics.

There is not sufficient space to develop these ideas in detail here. I refer those who are interested to my forthcoming book "The Cosmic Blueprint".

Most scientists find the idea of organizing principles repugnant. I believe that this is due to centuries of influence of the Newtonian paradigm, the paradigm that gave us the 'clockwork universe' in which everything could be traced back to initial conditions. There is, however, a growing awareness that there are laws of complexity that simply cannot be reduced to the underlying laws of physics — the laws of simplicity. I cite the work of Prigogine on self-organizing systems, the work of Charles Bennett at IBM on quantifying complexity, the work on information theory, artificial intelligence and cellular automata, the study of model neural nets, the ideas of theoretical biology, the discovery of systematic regularities in so-called chaotic systems and much more. All these topics point towards a post-Newtonian paradigm, in which complex organization is recognized as a primary phenomenon, and not an obscure derivative of the physics of elementary particles plus initial conditions fixed aeons ago.

From the human point of view, perhaps the most exhilarating outcome of this massive paradigm shift is that the pinnacle of complexity — the human mind — is once again to be taken seriously. No longer are mental events — thoughts, emotions, sensations, volitions — to be regarded as mere epiphenomena that can ultimately be reduced to the activities of electrons in neural circuitry. They are instead recognized for what they are — fundamental aspects of nature, requiring those electrons to be sure, but requiring much else besides. It is my belief that the new physics has restored to Man a dignity and purpose that the old physics robbed him of. The world paradigm of Newton, which served so well to advance physical science for three centuries, but inadvertently inculcated an obsession with reductionism, has now run its course. Three hundred years on, Man and Mind are once again emerging as central aspects of cosmic reality.

Ecodynamics: Life beyond the Newtonian paradigm

by

Peter M. Allen

1. Introduction

In reality, economic change is just one aspect of the more general question of evolution. The parallel had already been recognized by several of authors who have argued convincingly for the idea that economics should be understood on the basis of the 'evolutionary paradigm' , rather than that of the more traditional assumption of equilibrium, or of deterministic mechanics [1-4].

But this seems to be only the first step in the recognition of the fact that it is our lack of understanding of creative processes, adaptation and evolution itself which is the core of the problem. What we are really faced with is an evolving complex system, and the creation, acceptance, rejection, diffusion or suppression of innovations and technical changes cannot be considered in terms of economics, separate from history, culture, social structure, the ecological system and so on. That we should have ever attempted to do so is a symptom of our past unwillingness to 'grasp the nettle' of the holistic, dynamic, more-than-mechanical nature of the real world[5].

The very idea that areas of study can be hived off into separate domains in which 'closed' sciences can be constructed seems based only on organizational convenience, not on what may be seen in reality. Economics is merely one aspect of a human system. Cultural habits and rituals, music, technology, beliefs, psychological and biological needs are others of similar order. Ultimately all 'economic' decisions must be based in this wider reality in order to both reflect and affect these broader areas. Human values underlie prices, and either as individuals, or in measures of collective welfare, the monetary and the non-monetary must meet and interact. Any action will have direct effects on many different aspects of human systems, and these in turn will influences others, and so on in a complex chain of responses which defies simple, intuitive evaluation.

It is not enough that we should try to understand economics in evolutionary terms (though apparently this alone is considered dangerously radical by most economists), but rather that economics should be seen as just one aspect of evolving, complex systems. And if this is the case then a proper understanding of innovation and technical change can only come from improved knowledge about the general problem.

What then, is the science of evolution? What does it have to offer as a basis for the discussion of the discovery and diffusion of improvement and adaptation and what laws from it can possibly apply?

2. Newtonian Clocks and Darwinian Watches

Until recently, the only answer to such a question would have been that which is offered by theories of evolution based on the ideas of Charles Darwin[6]. But these ideas, although certainly correct as far as they go for biology, present evolution simply as the fruit of selective forces acting on randomly occurring mutations. The theory is not really predictive, but is instead a plausible explanation for what is observed. If some animals are observed to behave in a certain way, then it is assumed that a mutant once arose which behaved in this way, and that the innovation proved to be advantageous. The behavior must have been selected for, and that is why we see it... While Darwin's theory represented a tremendous step forward in the biological sciences, its connection to physics was tenuous, and it was simply assumed that physics and biology applied to quite distinct domains.

In Newtonian science, a system was understood by identifying its 'parts' together with the causal connections between them. The resulting assemblage of mechanisms then constituted a model of the system, and provided a tool for understanding observations and making predictions.

This idea reflected and confirmed the notion of the universe as a kind of giant 'clockwork' mechanism, conceived of and set in motion by God, and running according to immutable laws. Science was about discovering what these 'laws of nature' were, and hence revealing the intricacy and power of the Creator's work. And science succeeded in this quite brilliantly. Two basic assumptions were founded. In the absence of friction (planetary motion, for example) movement was unchecked and could go on for ever. There was no net effect from such movement, and there would be no way of telling whether a film of such events was being shown forwards or backwards. Such movement was reversible.

But with the dissipative processes of friction for example, initial concerted motion would eventually be dampened until the system reached thermodynamic equilibrium, such that all its initial high grade energy had been dissipated into random, thermal energy. This was an irreversible, pre-determined progression towards equilibrium, and the final state could be predicted as the maximum of the appropriate thermodynamic potential. The image here is of a universe gradually 'winding down' as it uses up its initial potential.

However, evolution in biology or the human sciences, and more specifically, the understanding of the birth and diffusion of innovations in the modern world, is about creative forces. It is not so much concerned with the simple functioning of the existing system, although this is of interest. It is instead primarily concerned with how the system became what it is, and how it will evolve in the future. In other words, if the world is viewed as some kind of 'machine' made up of component parts which influence each other in causal connections, then instead of simply asking how it works, evolutionary theory must also be concerned with how it became what it is. Fundamentally, evolutionary theory is about the origins of qualitative change, and how the parts of a system came into being and are maintained.

Not so the Newtonian paradigm. It was concerned with mechanical systems, either running, or running down. At best, the existing structure is maintained in the Newtonian paradigm, but more commonly it is eroded away as it approaches equilibrium, and entropy increases. Any representation of creatives processes is entirely absent.

Despite this (to us) obvious shortcoming, the extraordinary success of Newtonian physics, and thermodynamics — vindicated every day in calculations for industrial processes — made it a very tempting theoretical framework on which to rest <u>all</u> complex systems. Thus, in the fields of economics, biology, ecology, anthropology etc, theories in which understanding was based on assumptions of equilibrium states, and a search for the 'appropriate' potential function which was assumed to <u>govern</u> the evolution of these systems (utility, fitness, efficiency etc).

But the real difference in approach between this Newtonian-Darwinian view and the new perspective of today lies in whether we think of evolution as being over, or as still continuing. The key issue is centered on the passage between the detailed microscopic complexity of the real world, which clearly can evolve, and any aggregate, macroscopic model of this. In economics, the passage from micro- to macro-economics was achieved by simply supposing that the system was at economic equilibrium, and therefore that the evolution was 'over'. Despite the fact that this assumption flies in the face of everyday experience, it has nevertheless been the foundation for the entire edifice of economic theory[7]. Although, in retrospect the acceptance and adoption of such an assumption may seem a little extraordinary, the underlying reason for its adoption was simple: there was no alternative.

Micro-economics might discuss the individual's and the firm's behavior; Simon might show the importance of limitations in information flow; and Schumpeter[9] might base his thinking on the role of entrepreneurs; but somehow the illusion that whatever these details were, their sum total was necessarily controlled by the competitive forces underlying economic equilibrium; and that this state of equilibrium expressed some kind of optimal use of resources, some kind of 'maximum economic activity, was still clung to. The image that this presents is one of evolution as a blind watchmaker[10], where the intricate machinery of the world is comparable to that of a watch. The cogs and bearings are the fruit of selection, in the past, from unspecified trial and error. Behind this is the idea that evolution is an optimizing force which has led to the survival of the individuals and organizations we see because of their functional superiority. In this way, the classical theories of economics, of evolutionary biology and of anthropological interpretation have been permeated by the materialist ideas of the mechanical paradigm of classical physics. Running deep in this is the idea of 'progress', of the rightful 'survival of the fittest' and of a natural 'justice' which must characterize the long-term evolution of a complex system.

However, equilibrium models based on these ideas have proved in practice to be quite unsatisfactory as a basis for decision-making. Despite an enormous investment in research into economic, ecological and social systems, these concepts have failed to provide satisfactory models, and our understanding of the evolution that we observe remains essentially based on 'experience'. The fundamental reason for this is that the basic paradigm — our whole way of thinking about such things — is wrong. The systems which we see around us are neither at nor necessarily on their way to thermodynamic equilibrium. The sunlight incident on the Earth makes this certain. All living things have evolved in a state of non-equilibrium! And for such systems evolution can lead to the emergence of structure and form, and to qualitative change even in relatively simple physical systems.

3. Self-Organizing Systems: The New Evolutionary Synthesis

The central question which arises is that in order to even think about reality, to invent words and concepts with which to discuss it, we are forced to reduce its complexity. We cannot think of the trillion of molecules, living cells, organisms, individuals and events that surround us, each in its own place and with its own history. We must first make a taxonomic classification, and we must also make a spatial aggregation. This is shown in Figure 1. On the left, we have the cloudy, confused complexity of the real world. Each part is special, each point unique. On the right is a model of that reality, in terms of typical elements of the system, where classifications and spatial aggregation have been carried out. But the point is that however good the choice of variables, parameters and interaction mechanisms may be, these only concern average behavior. If we compare reality with the predictions of our model, then we shall necessarily find that variables and parameters fluctuate around average values, and also that there is much greater microscopic diversity than that considered at the level of the macroscopic model.

By making the right taxonomic and spatial aggregations we can model present reality by such a system of boxes and arrows. If in addition we assume that **only** average elements make up each category, and that **only** the most probable events actually occur, then our model reduces to a machine which represents the system in terms of a set of differential equations governing its variables. But such a machine is only capable of functioning, not evolving. It cannot restructure itself or insert new cogs and wheels, while reality can! And this is because of the differences between the left and right sides of Figure 1, which must mean that the key to understanding evolution lies in what has been taken out from complex reality in order to reduce it to the right hand section of the model.

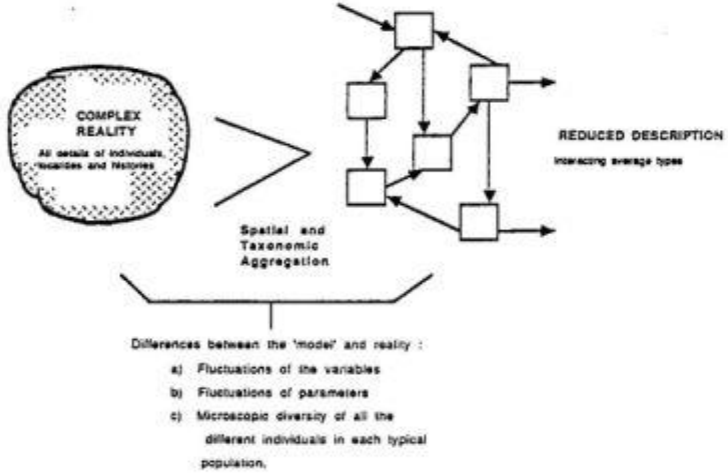


Figure 1. Modelling, and even thinking about a complex system necessitates a simplification into categories, which constitute the system. We make a 'mechanical' replica of present reality. But evolution concerns change in this structure — new boxes and new arrows.

Clearly therefore, evolution is due to two things. Firstly, to the effect of non-average values — fluctuations — of variables and parameters, and secondly, to changes introduced by the microscopic diversity which underlies the 'taxonomic' classification of the model. Let us consider these in turn.

4. Dissipative Structures — The Origins of Complexity

The work of many authors on self-organization and synergetic phenomena has demonstrated the fact that for systems far from equilibrium, basic physical non-linearities can in fact amplify fluctuations of variables and lead to symmetry breaking instabilities in which structure and organization appear; or if already present, evolve qualitatively[11-14].

Let us briefly describe a simple example of convection in a fluid which is heated from below. Initially, for weak temperature gradients, heat passes through the fluid from the bottom to the top by thermal conduction alone. However, as the temperature at the lower surface is increased, at a critical value, something quite remarkable happens.

Suddenly, the fluid itself starts to move. Thermal energy is now transported 'bodily' by the fluid itself in a convection process. But the movement is not just a general random drift, uniform throughout the system. Instead, a remarkable pattern of regular hexagonal convection cells appear spontaneously in the fluid, which moves upwards in the center of each cell, and downwards at the edges (see Figure 2).

In fact, as the temperature is further increased a whole series of successive patterns appear in the system, until finally, for very strong thermal gradients, complete turbulence occurs and no structure can any longer be observed.

The pattern which we observe, which involves the coherent behavior of trillions of molecules, is stable but does not necessarily express any particular 'optimality'. Does it give maximum heat transfer between the upper and lower surfaces for example? Is it the most efficient flow pattern possible, thus minimizing dissipation of thermal energy as it moves through the system? Or, on the contrary, is it the pattern of maximum dissipation, taking the most energy out of the heat source?

Even for such a simple system, **we are not able at present to answer these questions.**

This is a fundamental point to which we shall return. In systems which evolved to thermodynamic equilibrium there was a potential function which governed the evolution of the system. Either the entropy or the free energy imposed a deterministic relaxation process towards a pre-determined equilibrium state. And this was where physics got its powers of prediction from. But non-equilibrium systems achieve some kind of autonomy and freedom which means that they become 'creative', generating structure and complexity. The price which we pay for this, however, is a loss of predictability. Many other examples of such behavior now exist.

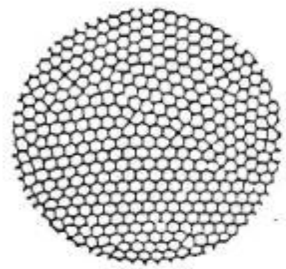


Figure 2. Beyond a well-defined critical temperature gradient, the Benard convection cells appear spontaneously.

In reality, we find that the equations which describe the average evolution of the variables really only specify a tree of potential behaviors. This branching tree of potential structures is typical of non-linear dynamic systems, and is called a bifurcation tree. Different branches of solution differ from each other qualitatively, i.e. they have distinctive characteristic symmetries, which means essentially that they have different forms. And yet all of them may be generated by the same simple, unchanging scheme of average kinetics — providing that it is non-linear. Which pattern is actually observed in a particular experiment cannot be controlled from the outside. While the external parameters can be fixed at the boundary, and may limit the actual choice, the fact remains that it is the system itself which 'decides' which of the possible patterns it will in fact adopt.

And really this 'choice' is made by the fluctuations which are present in the system. And this confirms the deduction made above that the key to evolutionary change lay in the differences between reality and its average representation. Because of fluctuations, the real system is always in fact probing the stability of the particular situation, and depending on which fluctuation occurs at a critical moment, the system will move to one or another of the stable behaviors which are possible. The real world is therefore much more 'lively' than its mechanical representation in terms only of average events occurring for average types. Symmetry-breaking transitions can occur spontaneously and so truly new structures can be created. In this fact lies the real source of innovation in the physical world.

However, in physics and chemistry, the elements of the system are atoms or molecules, these are essentially identical and incapable of internal re-organization beyond that fixed by the chemical transformations. But in the living world, we must examine the possibility that the internal structure of the individuals or elemental objects themselves could evolve in time. Indeed, these elements could themselves be dissipative structures in competition for the energy and matter that they require to maintain and transcend themselves.

In this connection then, it is the existence of microscopic diversity and modes of individual liberty that must be discussed.

5. Evolutionary Drive: The Role of Noise and Error-Making in Evolution

Studies concerning dissipative structures, and the self-organization of systems have largely concentrated on the aspects discussed in the preceding section, while the possible effects of microscopic diversity have been relatively neglected. In some very recent work[15], however, it has been shown that his too is of major importance.

In simple ecological models of competition we have examined the effects of 'error-making' in reproduction, which we suppose on average to lead to less efficient individuals. Nevertheless, as is summarized in Figure 3, evolution retains the 'error-making' population rather than one with perfect reproduction. In an evolutionary landscape of hills and valleys representing levels of functional efficiency of different possible organisms, it is the error-maker who can move up a hill, eventually out-competing a 'perfectly' reproducing rival. And this despite the fact that at each and every instant it would be better <u>not</u> to make errors, since the majority of these are loss-making.

This work shows that evolution does not lead to optimal behavior, because evolution concerns not only 'efficient performance' but also the constant <u>need for new discoveries</u>. What is found is that variability at the microscopic level, individual diversity, is part of the evolutionary strategy of survivors, and this is precisely what mechanical systems representations do not include. In other words, in the shifting landscape of a world in continuous evolution, the ability to climb is perhaps what counts, and what we see as a result of evolution are not species, or firms, with optimal behavior at each instant, but rather actors that can <u>learn</u>!

Because of this, at any moment behavior in the system itself will not be optimal, because of the existence of apparently random or highly eccentric behavior, which at that time is meaningless, and on average, loss-making. However, in order to maintain adaptivity to the environment some stochastic, risk-taking behavior is retained by evolution. In brief, evolution is both driven by, and leads to microscopic diversity and individual variability. Selection viewed at the macroscopic level of averages cannot destroy the microscopic diversity. Indeed, it is just this diversity which drives evolution!

The fluctuations, mutations and apparently random movements which are naturally present in real complex systems, constitute a sort of imaginative or creative force, which will explore around whatever exists at present. Selection, or rather the dynamic mechanisms of the system operate on these attempts which will either regress, or on the contrary will sweep the system off to some new state of organization.

We can liken this ecological problem to the situation of many small firms competing for a particular market. In some of these, the present state of technological know-how is translated into a very clear plan of production which is put into operation with little or no error. In others, however, the plan is less clear, and variations in production technique lead somewhat randomly to a product of variable aspect, and costs. Of course, most of the errors will give rise to less satisfactory products, but a few of them will be improvements. The information created by this random probing can be used by the discoverers to change their product. If the new production plan is too perfect and clear, then no more discoveries will be made. What is really required is the right compromise between local 'experimentation' (resulting either from error, ignorance or research) and efficient production techniques.

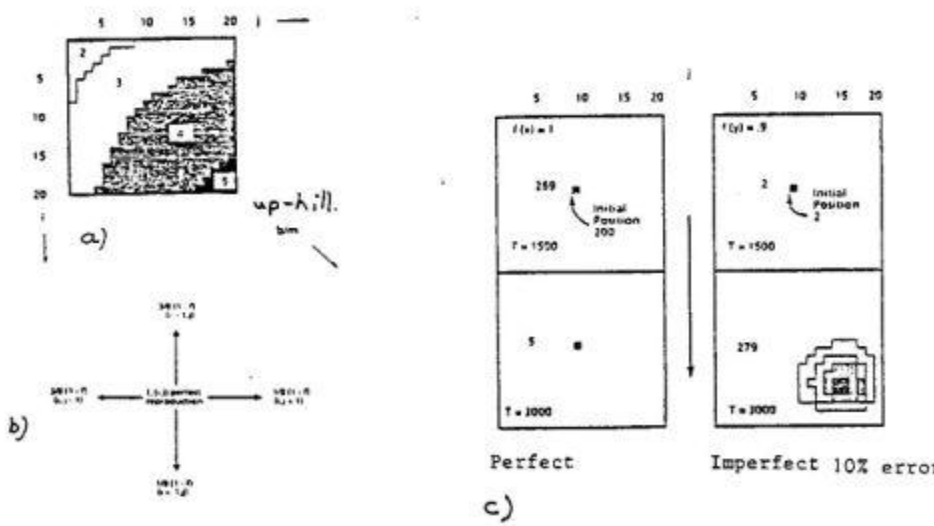
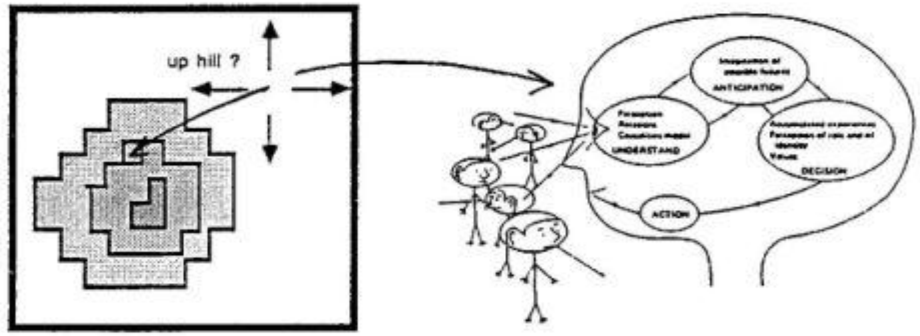


Figure 3. In the simple landscape a), the result of competition between perfectly and imperfectly reproducing populations (as far as phenotypical parameters are concerned, b)) is shown in c).

Also, because in general, each firm is in competition with others, technological and organizational changes will lead to responses and counter measures, to an 'arms race', with no obvious end. Evolution therefore is a continuing process, and that is why selection favors individuals and firms which maintain the ability to adapt and learn new things.

In the biology of simple beings, genetic reproduction ensures that the 'information' about a successful strategy resulting from advantageous genetic variability can only be passed on to the descendents. But of course, an entirely new phase of evolution is reached once information can be 'perceived' and imitative modes of behavior are possible. The fulcrum of evolution passes from genetics to perception-judgement-behavior. For higher animals, the diverse personalities and circumstances of individuals leads to experimentations which, when successful, can be imitated by others. For this however a gradient of some measure of success must be defined in the mind of each individual concerned, and here, selections will act upon the diverse systems of values, leading to cultural evolution. Once again, if conformity is too strong, then the creativity of the system will decline.



a) A behavioral space exists, but b) it is difficult to know what is advantageous.

Figure 4. In human systems, behavior is no longer predominantly shaped by natural selection. Instead, it is affected by the perception of success and imitative processes.

Such a mechanism represents a much faster mode of evolution than that which required the physical elimination of the 'unfit'. But in this new more rapid evolutionary mechanism the discovery of better strategies, and the concealment or diffusion of this information become the key elements and evolution moves to a new focus. Given the complex complementarities (division of labor, family roles, complex loyalties) and competitiveness of the human situation, as well as the existence of processes with long time scales, we see that a very important element of evolution concerns what individuals decide to consider as being advantageous. In a complex social system, any single cultural consensus as to what goals are, if strictly adhered to, would greatly reduce the diversity of the system and make it more fragile and less capable of adaptation. Clearly, the corollary in human systems of the genetic diversity underlying biological evolution is the existence of many different views and values. This will lead to diverse behaviors and explorations. Information creation and channelling will be key factors in obtaining the right compromise between a rigid 'mono-culture' of clear values and duties, and the chaos of totally disparate individuals with no consensus at all, unable to act together.

The concepts of innovation and the diffusion of technical change are profoundly rooted in these basic evolutionary issues, and in the next section, I shall briefly discuss some practical applications of these ideas, in order to point out the way in which these new paths might be explored.

5. Generic Studies

Science is about finding generic statements and widely applicable principles which can be used to understand particular systems, and this should be distinguishable from simply making descriptive models in case studies. The models described below are based on mechanisms and processes which underlie appearances. They discuss global behavior which results from microscopic processes, and recognize the 'cognitive' dimension that must be taken into account when considering human behavior.

The first example to be only briefly described here concerns the development of mathematical models of fisheries. This may seem to be a subject rather far removed from that of 'hi-tech' and 'silicon valley' , but it will become apparent that it is an example which makes the basic issues and problems very clear. It is an 'archetypical' complex system, with many aspects: the physical behavior of the ocean or coastal waters; the complexity of the marine ecosystem with its many levels and species in constant evolution; the behavior (and technology) of fishermen deciding what and where to fish; the needs and directives of the processing industry which buys much of what is landed; the need for employment both in the fishing and processing industries; the demand from both local and foreign consumers and the competition with other foodstuffs in the international and domestic marketplace.

In several recent papers[16,17] these applications have been described. Here I will briefly outline some of the main features.

The first and simplest consists of a dynamic model of a fishery corresponding to the scheme shown in Figure 5. Contrary to the customary management models, the complexity of the fishermen's behavior over time has been included, and that of the market. Also, the model is dynamic, and is based on the effects of mechanisms of growth and decline in fish populations, fishing fleets, fish prices and fish markets, whereas the models used presently assume that these are in equilibrium!

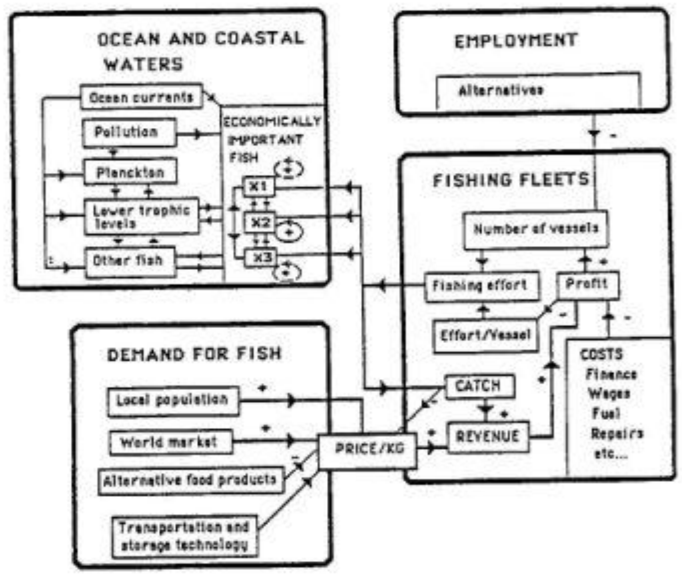


Figure 5. The dynamic system of our fishing model.

The first important result concerns the qualitative nature of the behavior observed. If we run our mechanical model of Figure 5 purely deterministically from some initial condition, it will tend to a steady state of equilibrium. It may take some 40m years to get there, but there will eventually be an equilibrium. Previous management strategies are based on the relation between this equilibrium state and the fishing effort applied by the fleets! However, if we insert the reality of environmental fluctuations, which affect the yearly production of young fish, then the result is dramatic. The system amplifies these short term, random events into large, long term (17 year) cycles of 'boom' and 'bust'. This in fact agrees with reality, for the Canadian fisheries which were the subject of our model. This bears out the points made in Figure 1, where an understanding of the qualitative state of the system cannot be obtained from the mechanical model. The effects of fluctuations must be considered. Furthermore, if we add in the effects of microscopic diversity of behavior on the part of fishermen, and the economic success that accrues to those with faster reflexes and better technology, we see that in fact we can understand the long-term evolution of most fisheries, as they move from the stable exploitation of a large stock, to the unstable, over-exploitation of a much reduced one.

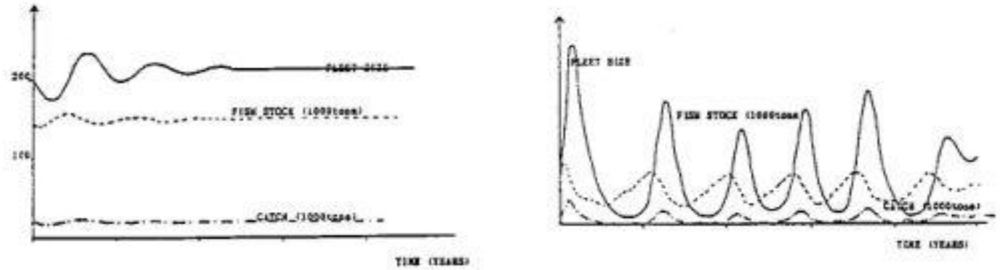


Figure 6 a. Without fluctuations   6 b. With fluctuations

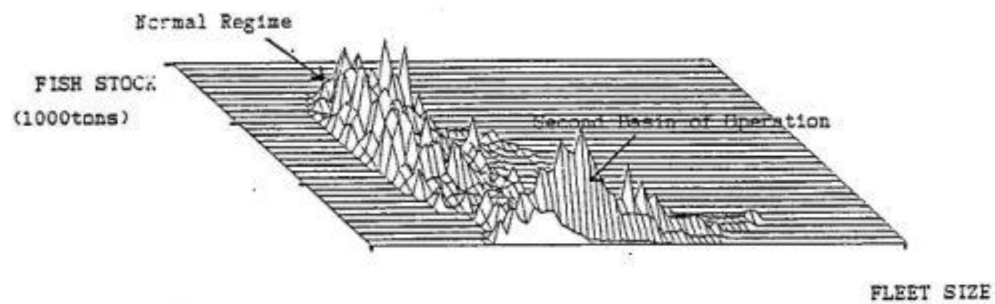


Figure 6. Two possible regimes of operation of a fishery. In one we have 'normal' cycles of boom and bust, based on fish stock variability, and in the other the fish are a rare luxury of a very high unit value.

Also our model shows that two possible regimes of functioning of the fishery can exist. The first is the relatively normal one of 'boom' and 'bust' cycles referred to above. The second occurs at some time during a system 'crash'. If the elasticity of demand is sufficiently low, the price of the rare fish caught rises dramatically, permitting fishermen to earn a living from the tiny stock. This means that they continue their efforts and the stock remains small, and prices high. The fish have become a 'luxury' product, and the industry may well survive, but as a source of food, the resource has largely disappeared. All of these results give a far greater understanding of the effects of different policies, and also the different regimes possible.

In another more detailed fishing model however, we generate the spatial behavior of the fishing fleets and the fish stocks, and showed how extraordinarily complex behavior emerges. This model focuses on fishermen's behavior, including the manner in which they make decisions about where and what to fish.

Our model has two sets of equations, one for the fish in each spatial zone, and the other for the boats. We shall focus briefly her on the latter. Interested readers should consult the original publications for more details. The set of equations describes how the numbers of boats of a given fleet, situated at a point, changes over time due to two terms: an economic 'selection' where revenue must exceed costs; and a term governing the movement of the boats to zones of high expected profit.

For us, the important point is that these expected returns can only be formulated in the light of **information** about the catches that are being made in the different zones. Therefore, it requires both the presence of boats making catches in that zone, and the flow of information between those boats, and the boat that is considering where to fish. This gives rise to a positive feedback mechanism which will shape the spatial pattern of fishing effort. This pattern over time will in fact be 'explained' not according to an optimal rationality, but instead according to history, accident and communication.

However, apart from this fairly obvious rational term, there is the dependence of attractivity, and decision on the **personal and beliefs** of the skippers. How carefully do they weigh the evidence? We can identify two extremes. At one extreme, we have "Stochasts". They pay absolutely no attention to economic rationality, and simply diffuse at random. At the other extreme, we have "Cartesians". These weigh absolutely precisely the information available, and move with probability One to the point which is most attractive — even if it is only marginally better than elsewhere.

Obviously fishermen fall somewhere between these two extremes, but nevertheless, the idea of Stochasts and Cartesians seems to capture a basic truth about people. In the Canadian fleets, as elsewhere, we find risk-takers who make the discoveries of new fish aggregates and the others, who are content to rely on the information generated by the risk-takers.

What our model allows us to do is to explore the evolution of such a system, and we find that a population of Cartesians alone survives poorly on a small part of the system's potential, never exploring beyond this. However, although Stochasts can beat Cartesians, they remain too dispersed to exploit their discoveries efficiently. A most efficient strategy for the fishing fleets as a whole is to have Cartesians who spy on Stochasts. We can show that providing say 10% of the information about catches gets through to them, they succeed in creaming off the good fishing areas discovered by the Stochasts and make a good living. Of course, all kinds of complexities such as spying, lying, communicating in code, code-breaking, alliances etc can emerge, and this has been reported on elsewhere[18], but these results are of fundamental importance in our discussion of evolution, and of economic innovation and enterprise.

The key point about these models is that they attempt to consider the globality of the processes taking place in a given region, and also the 'cognitive' aspects of the decision-making behavior. They are really examples of a **regional** science where the ecosystem and the economic, social and cultural realities and values are brought together in a unified framework. A similar initiative, with different emphasis underlies our work in developing evolutionary models of urban systems.

In this work dynamic spatial models describing urban and regional evolution of socio-economic structure have been developed[19,20]. Vastly different spatial scales were modelled from that of a city like Brussels[21],to that of the entire continental United States[22], and simple versions of these models have also been applied to some French cities[23].

The models consists of sets of interacting equations, each of which represents the change occurring at a particular point in the different activities and populations located there. In the space available here we shall only attempt to outline the main features of our model, and interested readers should consult the original articles. We try to model the globality of the processes operating in a region, although here the stress is laid more on the economic, demographic and urban aspects rather than the ecology, and the natural environment.

There are 4 basic mechanisms at the heart of our dynamic equations:

- the distribution of population for a given distribution of employment through choice of residence location, taking into account the transportation networks, available housing, and the different qualities of service and environment.This is evident from the daily flows of traffic to and from work.

- the patterns of demand for goods and services coming both from the population and from economic activities which require components and services. This is evident in the flows of goods and services from the inputs to production to the final consumers.

These first two mechanisms are concerned with functional flows reflecting the **operation** of the system. But in fact there are at least two possible patterns for each flow. First, there is the real, observable values of each flow at a given time. Second there is the **potential**, or desired pattern. If these were identical, then clearly there would be no evolution and the system would be at equilibrium. But if there are differences in various sectors at particular points, then we suppose that this will drive evolutionary changes in the spatial patterns.

The third and fourth mechanisms result from the **perception** by actors in the system of these differences between 'potential' and 'real' values. Of course these changes are imposed in addition to those due to normal demographic processes.

- demographic changes and the perception of the pattern of employment and housing opportunities generating migratory flows of population.

- the perception of the pattern of economic opportunities and the distribution of investments.

At each moment, the model calculates the **desired** spatial distribution and number of the different types of actors at each point in the system. It may differ from the actual distribution observed. This may be either because they have never been equal, or because even though they were at one time, changes e.g. spatial patterns, technology etc) that have since occurred have upset the equilibrium. The differences between real and potential values create a pattern of 'opportunities' and 'dissatisfactions', and if they are perceived they lead, through the third and fourth mechanisms, to redistributions of employment and population. But this in turn modifies the pattern of potential for homes, and for goods and services in the next time period, and so a complex chain of successive readjustments is set in motion.

Decisions are taken in response to the information concerning patterns of opportunity and dissatisfaction, as we discussed in the section above about the creation of information by Stochasts, and this can only be modelled by calculating some **unobservable potential**, comparing it with reality, and supposing that it is responsible for the changes which occur.

Figure 7 shows a simplified view of the interaction scheme of our model. It shows how the population and employment of each spatial zone change in the manner we have described above, but in the model, economic activities and different populations can be disaggregated in whatever way is appropriate for the problem. In essence, the computer calculates at each instant how many residents and how much economic activity of each kind would like to be in the zone, given the potential demand and the advantages and disadvantages of the zone. It compares this with the numbers that are actually there, and the differences (if we suppose that they are perceived) then drive the shifts in investment and population.

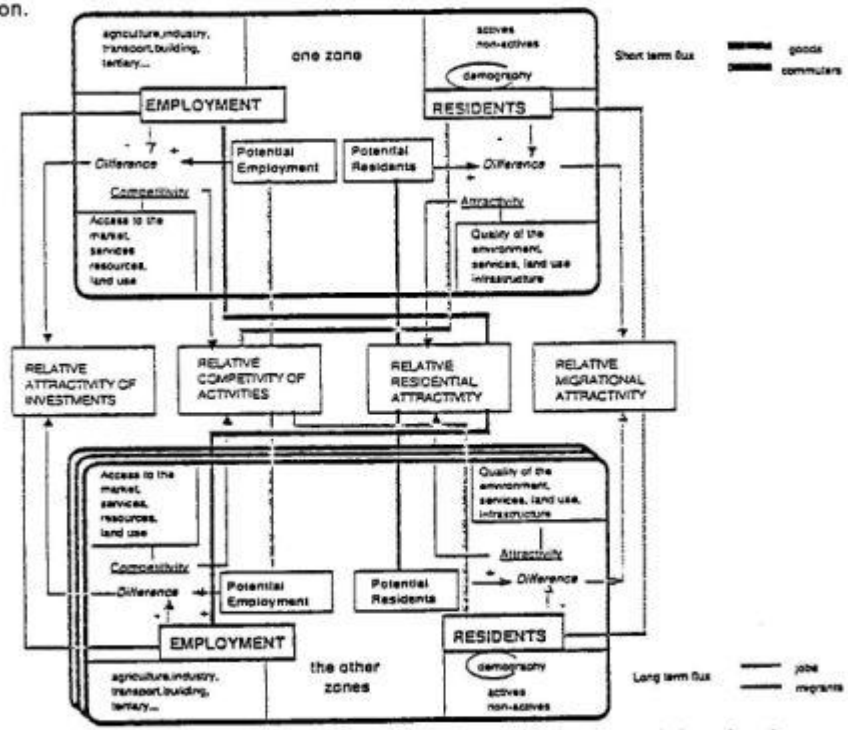


Figure 7. The interaction scheme providing a global framework for the evolution of a city or region.

As an example, let us consider the changes which occurred in employment in the manufacturing sector in the different provinces of Belgium. This is taken from a study which we have made of the 'evolution' of Belgium from 1970 to 1985.

In 1970, we know how many jobs there were in this sector in each province. The economic demand responsible comes not only from different places, but also from different sectors of the economy. Moreover, economic activity requires input materials and factors which again may come from different places and sectors. If we are to assess the potential for manufacturing in each province, then we must calculate its competitiveness as compared to the others. This assessment will therefore depend on the 'input' costs for that activity in that location, and also distribution costs to clients. Activities are usually also to some extent both clients and suppliers in the system, and their competitiveness must take this into account.

Information concerning the direct exchanges between the different variables are obtained from the Input/Output matrix for the Belgian economy (Figure 8). Thus, for example, the manufacturing sector nationally is generated by export markets (37%), by final consumption by the population (36%) and by firms within the sector itself (8%). Other connections are too weak to be of significance in the figure. On the other hand, the manufacturing sector buys 58% of agricultural production (food processing falls into this category) and 11% of the transport. From this, we can suppose that it is possible to calculate both the total demand for this sector and also the total generated by this sector for any particular province.

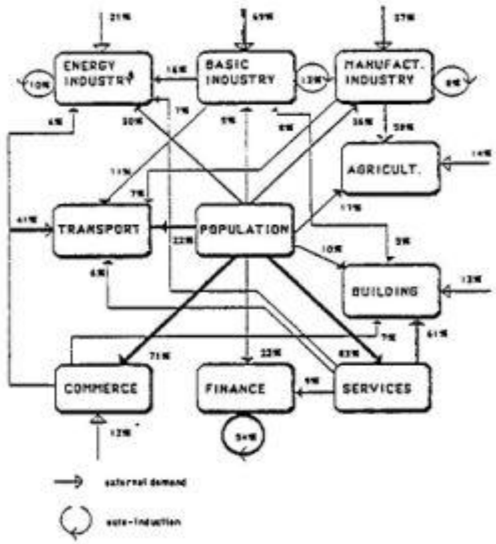


Figure 8. The aggregate interconnection between the different variables of our model of Belgium, taken from the Input/Output matrix.

Instantaneously, the total economic demand for manufactured goods can be calculated for each province, and the amount captured by each one can be estimated by considering its competitiveness among the others.

This includes the external factors resulting from inter- and intra-sectorial exchanges of production input and output which are characteristic of each locality, and therefore can model the cooperative/competitive dynamics of industrial and service complexes.

Our model then goes on the calculate in a similar way the changes that will occur in each of the different sectors of employment and in the population resident in each zone. After this, the computer starts the whole calculation process again for the next time interval. In this way, the distribution of population responds to that of employment, and this in turn responds both to itself, and to the distribution of population. Changes in either will have repercussions along these channels of response, which reflect sectorial complementarity and spatial proximity.

Running the model over a long period therefore generates a picture of the evolution of each employment sector and population in each spatial zone. In doing this it also generates pictures of the changing flows of commuters, raw materials, intermediate components, finished products and services between the different sectors of the economy and different locations. The resulting pictures of evolution can then be compared with that actually observed, and the parameters which characterize the different activities adjusted until they produce an evolutionary picture which agrees with reality.

Figure 9. The differences between potential and real manufacturing capacity in the provinces of Belgium explains the patterns of growth or decline observed at that time.

In each aggregate category, (manufacturing, services etc) there will in fact be parts which are growing and others in decline. Evolution results not from the average behavior shown in the input/output table, but from the relative growth and decline of small subsectors which make up the real microscopic diversity of the system. The important point then is to identify the parts (subsectors, particular zones) which are growing, and to specify more accurately their particular 'input-output' matrices. In this way, we can focus on the 'growth system' in the economy, and facilitate the processes of technical change and innovation.

We can also examine the extent to which evolutionary processes are captured by a model such as ours. There are four basic kinds of evolution which can influence an urban or regional system:

a the spatial diffusion of population and activities according to perceived opportunities,
b the changes resulting from technological progress, changing input and output requirements and costs,
c entirely new activities resulting from some technological breakthrough; changes in people's expectations and desired life-style.

Our model can in fact deal quite well with the first two of these. The system evolves through the perception of opportunities by the different actors. These may be due to earlier changes, to technological advance, demography, or to changing terms of trade. Our model makes the input/output table dynamic, but underlies the fact that what really matters for evolution is what is happening at the 'leading edge' of all this. It is in the growth of subsectors and the inductive loops of these that the future lies. The model therefore serves as a framework within which to identify and study these important diffusing disequilibria.

The third and fourth types of evolution are not really in this model and it is difficult to see how they could be included in any precise way. Entirely new products cannot be anticipated easily, or they would not be new. Neither is it easy to say when and in what way people may modify their behavior their values, and adopt new goals. What could be done however, would be to explore the consequence of some possible change. If this were done, some estimate could be made of the advantages for individuals making such a move, and from that it would be possible perhaps to estimate whether such a change was really very likely or not.

7. Conclusion

The fundamental point raised in this paper is that discovery and innovation can only be achieved by going beyond the present system. We require Stochasts who, for whatever reason, do not respond simply to the information which exists about the present returns on effort. The Cartesians on the other hand, are the backbone of the system. They represent the norm and will also be the ones to push any particular activity to its ultimate in excellence. The success of the overall system will be determined by the balanced existence of the two types, and the manner in which new information is channelled into the system. While the adaptive capacity of a system lies in its Stochasts, the stability and efficient performance resides with its Cartesians. A system in harmony must allow discoverers to recuperate their exploration costs, or risk losing them altogether, and this will depend critically on the period of 'monopoly' allowed them.

A period of expansion follows a discovery, as the spread of information leads to increased demand and economies of scale. However, after some time either the market begins to be saturated or the resource required starts to get scarce. Either way, competition intensifies and a period of 'rationalization' follows when investment is directed to making production more efficient, usually decreasing employment in the sector. Competition increases, and only the discovery of new activities and products, made perhaps, by the displaced 'stochasts' can save the situation.

Usually Cartesians will not listen to news of discoveries while things in the established areas are not in crisis. Hence, venture capital may well be lacking during a period of prosperity. When a crisis approaches however, the first reaction is the Cartesians to try to do what they already do, but better! The more they do in this line, the greater the crisis will be when it finally comes. At this point and only then will information concerning discoveries be acted upon by all those still in a position to act. New structure will emerge, new job definitions and new specializations will come into being and start to fossilize, as they 'hill climb' up to apparently greater rationality and efficiency. And so our model suggests the existence of a 'long wave' or Kondratiev cycle, and offers a real possibility of its analysis.

This underlines the aim of this approach. It is not intended to predict the future. Instead, it is intended to offer an integrating framework into which existing knowledge can be placed. With this, the future can be explored and better imagined. However, the real world is really much richer than any model, and therefore will always manage to evolve in ways that have not been included in this model. This is not a reason to abandon model-making, but rather the opposite. Without the model, we would not be able to order the system to an extent sufficient to realize that something inexplicable was occurring. With it, we can become aware of the emergence of new mechanisms or factors and we can then search for the best manner in which to include them. The model we have of a particular situation will probably always require modification because the real world is itself evolving.

The real message of the new concepts in science is that change and disequilibria are probably more natural than equilibrium and stasis. Those who can adapt and learn will survive. And this is dependent on their creativity. For example, when we suppose that change is a response to perceived opportunities, then it is saying that the potential for growth and diversity in any region or city depends to an extent on the **imagination** of the people that live there. What openings for which activities do they perceive? This will depend on the finer details of their history, culture and social interactions. Generally speaking, microscopic diversity resulting from the mixing of cultures, conflicting doctrines and individual freedom will be an important ingredient in this response. In other words, technical change and economic evolution are related to factors such as originality, risk-taking and creativity in a population.

Hopefully, the ideas discussed here can help to lay the foundations of a new synthesis in the human sciences. Creativity and change find a place together with structure and function in this new scientific paradigm. Although the reassuring feeling lent by determinism has had to be sacrificed, in return we now have a unified view of the world that bridges the gap between the physical and human sciences. And it is not true that this represents a final reduction of human and social phenomena to the mechanical dictates of physics! Instead the latter has been elevated and had had to abandon its immature search for absolute certainties. What we now see is a multi-faceted world, perceived in different ways evolving through successive states of organization as a result of non-average events and individuals. Instead of being limited to approaching human systems from a descriptive or ideological standpoint, science now offers us a mathematical basis on which to understand how such complex systems came into being, and how they may evolve in the future. The next decade will see a rapid growth in research aimed at exploring this new and exciting path.

Acknowledgements

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Theses of a New Reformation
The Social Fallout of Science 300 Years After Newton

by

Harlan Cleveland

I.

The bold political thinking that led to the Constitution of the United States 200 years ago was rooted in an even bolder leap of the human imagination just a hundred years before.

That was when Isaac Newton, standing on the shoulders of Copernicus and Kepler, proposed a force of universal gravitation to explain why the planets revolved around the sun in elliptical paths. This force, he figured, loses effect by the square of the distance. that same force, he also guessed, keeps the moon in motion around the Earth, holds our feet on the ground, and causes objects (such as Newton's famous apple) to fall to Earth. This is still a pretty good guess.

But Newton, in 1687, could not guess that the scientific revolution he helped start would in time become a kind of secular religion, the scientific method binding together an influential new international priesthood.

He certainly did not foresee that in a scant three centuries, people might through science acquire the power to do more to their natural environment than nature does to, and for, people. Yet this is where we are today. This ironic anonymous couplet says it all:

> Strange that man should make up lists of
>   living things in danger.
> Why he fails to list himself is really
>   even stranger.

II.

Isaac Newton's Principia is sometimes taken as the beginning of the Scientific Revolution, the watershed that separates the modern from the medieval era.

In the West, that moment in history was also an early milestone in the long sliding slope for the medieval Church. Science energized a cultural Renaissance, expanded economic potentials, and made possible a politics of pluralism and participation that swept away the divinity of monarchs and eroded the infallibility of the Pope. In the non-Western world, craft-based technology colonized the Americas, Africa and much of Asia; opened the glued-tight culture of the Japanese islands; and for a time even mesmerized the Chinese, inheritors of the world's wisest traditional culture.

In medieval times, Church and State were linked as master is to servant. Monarchs assumed or asserted a divine right to rule. The State was an expression of the Church, the instrument of public administration in secular affairs for a superior authority run by men who spoke for God.

In the three centuries since Newton, science has elbowed the Church aside — all churches, reformed and otherwise — to become a kind of secular religion. Science gradually took over the functions of the medieval Church, to establish an educated priesthood of those with access to closely held mysteries; to legitimate those who held the posts, exercised the perogatives and enjoyed the perquisites of economic and political leadership; to bless the orthodoxies in which people were permitted to believe.

In time, Science and the State came in their turn to be linked as master and servant. The source of legitimacy for statecraft is whatever looks properly scientific. Government officials, or those who seek public subsidies and permessos, must argue their case with the metaphors of physics, the methodologies of microeconomics, the mathematics of cost-benefit analysis, and discounted future values. What people want, how far they will follow the leaders, is ascertained by survey research, the scientific sampling of "public opinion". In the modern marketplaces of ideas, the means of exchange and measure of value are numbers. What can't be counted is treated as an "externality" — that is, a disturbingly relevant factor that just doesn't fit the current fashion in systematic thought and is therefore put on the shelf to think about later.

III.

We got into this fix because our thinking about society — about economics, business, politics, even about philosophy and religion — was mesmerized by the success story of "natural" science.

It was not until Newton had pictured the universe as guided by precise laws of motion, tending to harmonize the forces of nature, that John Locke found in "laws of nature" the foundation for human society. Adam Smith discovered an "invisible hand" to guide trade and industry according to the (natural) law of supply and demand, and James Madison wrote that a balance among "factions" might, like the counterpoise of heavenly bodies, provide a democracy with built-in self-control.

Eighty years after the United States of America was born in this Newtonian mold, Charles Darwin's theory of natural evolution made room for a nastier mode of social thinking. In this world view, unpremeditated struggle, wasteful and chaotic, replaced order and reason as the central dynamic.

The already rich and powerful soon found in Darwin's idea an argument against compassion, a justification for cruelty and selfishness. If you were poor, that just proved you were unfit. (The theme still reverberates in today's welfare debate.)

After another half-century, along came Albert Einstein with his guess that matter and energy are aspects of each other, and his search for a general theory of relativity. Einstein was hardly what we would now call a "relativist". He was looking for physical laws that could be applied to all systems; in effect an absolute equation. But the notion that "everything is relative" became a powerful new social metaphor, popularizing the behavioral approach to social science and further eroding churches that depended for their clout on moral discipline and unquestioning faith.

It became quite respectable to believe that eternal verities might well be proven wrong by further scientific study — the students meanwhile suspending judgement on whatever they might earlier have learned at home, in church or at school. the Pope, visiting the United States last year, encountered science-based skepticism at every whistle stop.

The global spread of social relativity may even have contributed to the growing conviction, in colonial and other less-developed countries, that the self-evident principles by which the suppression of subject peoples had been justified and their natural resources appropriated might in a new world view prove unjustifiable.

Since the 1960s, yet another new social outlook has emerged from the profound discoveries of the life sciences (the cracking of genetic codes, new ways of guessing what goes on inside a cell) and growing scientific interest in the linkage of biology, chemistry, physics, meteorology, economics, and geophysics to decipher food-climate-population-energy puzzles. Quite suddenly the evidence seemed overwhelming that everything really is related somehow to everything else, and word "ecology", used earlier in public management by John Gans and David Lilienthal, came into general vogue.

In a luminous essay about the messages cells send to each other, Lewis Thomas observes that, in order to sustain life, "using one signal or another, each form of life announces its proximity to the others around it, setting limits on encroachment or spreading welcome to potential symbionts." The Earth itself might be thought of as an "immense organism" where "chemical signals might serve the function of global hormones, keeping balance and symmetry in the operation of various interrelated working parts, informing tissues in the vegetation of the Alps about the state of the eels in the Sargasso Sea, by long interminable relays of interconnected messages between all kinds of other creatures."

Ecological science directs attention to the way varieties of life relate to one another, and the environmental "support systems" that make life possible. The key word, parallel to harmony, struggle and relativity in the earlier cosmologies, is now interdependence.

IV.

The revolutions of our time are still driven, more and more, by scientific discoveries and their technological progeny.

A dimensional change in explosive power has created dangers without precedent (Hiroshima, Chernobyl), has provided an alternative source of energy and additional tools for medicine, and has required fundamental rethinking of military strategy. By making it possible to invent weapons too powerful to use, science may even, by an accident of frightfulness, have placed a lid on the scale of human violence, for the first time in human history.

A breakthrough in understanding the inherited information in our genes has provided us with a vast array of biotechnologies, with application ranging from the correction of birth defects in an individual fetus to genocide with biological warfare.

Atmospheric gases, products of industrial civilization, may now be the agents of large and irreversible changes in the global climate. This "global change" could double back on human civilization, radically redistributing moisture and, in the span of a single human lifetime, inundating most of the world's great seaports.

Above all, the convergence of two separate lines of science-and-technology, that is, faster computers and more reliable wide-band telecommunications, is creating societies where the dominant resource is information; the dominant activity no longer the production and exchange of things, but the production and sharing of symbols.

Shortly before her death in 1946, Gertrude Stein complained that "Everybody gets so much information all day long that they lose their common sense." To regain our common sense, the informatization of society requires us to rethink the very fundaments of our philosophy; to rethink an economics in which value inheres in scarcity; rethink a governance based on secrecy; rethink laws based on ownership and rethink management based on hierarchy.

V.

These concurrent and interactive revolutions contain their own inner-directed ethic: the more we can discover, the better off we shall be.

Almost a century before Newton, in 1597, Francis Bacon had speculated (also in Latin) that "knowledge is power". Imbedded in the logic of science and technology is the buoyant optimism of Newton's harmonious equations: the orbiting planets of power which knowledge creates will somehow not collide with each other to the detriment of the human species. The logic is linear: as we decipher the riddles of nature, we must naturally give thought to the technologies the new science makes possible. Because the new technologies are possible, they also must be necessary. If the new technologies enable us to make new machines and processes, we must assuredly design, construct and deploy them.

But nowadays the mood is different. Modern societies no longer stand still for the uncritical translation of scientific insights in social dogmas. Science-and-technology has produced so much dirt and smog and ugliness, so many explosions and crashes in fail-safe systems, so much wasted weaponry and undisposable waste, that popular resistance to the "internal logic" of the scientific method grows louder every year, even though (so powerful is the metaphor of the scientific method) the objections themselves are expressed in the language of scientific rationalism.

If we are powerful enough to despoil the human environment, some say, we are surely rational enough to protect, conserve and even enhance it. If we can produce enough for all, why can't we distribute it more rationally? If we truly value differing traditional values, can't they be rationally studied, adapted to, and reconciled with, rather than overridden by, the standardizing "progress" brought about by science-and-technology?

Evidence of the new ambivalent mood, still mesmerized by science, but newly aware of technology, is all around us. In environmental matters it was symbolized and spurred 26 years ago, in 1962, by Rachel Carson's influential book Silent Spring. "The 'control of nature'" she wrote, "is a phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man." The following year, President John F. Kennedy caught the wave in a Commencement speech at American University: "In the final analysis, our most basic link is that we all inhabit this small planet. We all breathe the same air. We all cherish our children's future. And we are all mortal." In our time the Swedish microbiologist Carl-Göran Hedén puts it this way: ".....technology must be tailored to Man, if it is going to be of any use at all. If technology goes beyond the average man's comprehension, and in addition is governed by experts in distant places, this gives rise to insecurity and this, in its turn, breeds distrust and inaction."

In the United States, a growing body of laws, regulations and practices expresses the new mood. Estimates of environmental impact have become routine, industrial safety standards strict, the practice of birth control widespread. The nuclear power industry, which failed to do its homework on safety, waste and proliferation, was brought to a standstill by a handful of stubborn and knowledgeable skeptics. "Technology assessment", the ambition of distinguishing in advance the benign from the malign faces of new inventions and processes, is no longer an exotic idea.

Around the world the technological backlash has taken a variety of forms. It has penetrated party politics (the "Greenies"), business (baby formula, auto safety, smoking), public policy (clean water, acid rain, smog, aircraft noise), and international relations (arms control and agreements to restrain pollution and promote aircraft safety). Thinkers in developing countries have been talking (though governments are not doing much) about alternative modes of development that would not require the waste and unfairness which seem, in industrial society, to be the handmaidens of "progress". From time to time, a major man-bites-dog decision is taken not to manufacture and deploy something new even though we know how. For example, the U.S. Senate checkmated the project for a supersonic transport (the SST), and more recently the two superpowers agreed not to deploy anti-ballistic missile (ABM) systems.

VI.

What emerges as a prospect, 300 years after Newton, is a creative combination of human limits and human opportunities; the opportunities presenting themselves only if the human species can control itself. The emerging ethic of ecology is an interlocking system of human self-control. It is not "limits to growth" but limits to thoughtlessness, unfairness, and conflict (Figure 1, page 45a).

In one dimension, the "rich-poor" or "North-South"?? axis, an emerging ethic of fairness suggests a limit (A) to poverty, a minimum entitlement to human needs merely by virtue of being born into the human family; and also a limit (B) to the share which the most affluent person takes from a pool of resources which is flexible but finite. (The principle is familiar, even if the practice is uneven, in the progressive income tax system.)

In other dimensions, an emerging ethic of prudence suggests socially-determined limits (C) to the damage people do to their physical environment (air and water pollution, stripping of the land, thinning of the ozone layer); (D) to the dangers inherent in people-managed processes (family planning decisions, nuclear power plants, chemical reactions, traffic accidents, weather modification, genetic engineering); (E) to the rate at which people use up non-renewable resources (fossil fuels, hard minerals); and (F) to practices that affect the renewability of renewable resources (soil erosion, destruction of wildlife, overcropping of farmland, overcutting of forests, overfishing of lakes and oceans).

Still another dimension (G) limits the scale of conflict about fairness, about natural resources, about ideas, and about cultural identity. The arms available for use in these conflicts, which are not only the conventional and nuclear instruments of hideousness but also economic and monetary and psychological and chemical and biological and meteorological weapons, will no longer be in the hands of an oligopoly of so-called "powers". The nuclear technologies especially give everyone a common stake in limiting the extension of politics by military means. Factions and nations and regional or ideological blocs are going to have to bargain with each other without the option of turning to the nuclear weaponeers as a last resort, because the last resort is too liable to be <u>the last</u>.

VII.

Self-control is not an end in itself. It's not enough to set socially-determined limits to technological "progress", designed to mitigate its social fallout. The purpose of science and technology, of unleashing human curiosity and harnessing the human urge to invent and to innovate, is to contribute to the fulfillment of basic needs, material and spiritual, of humanity.

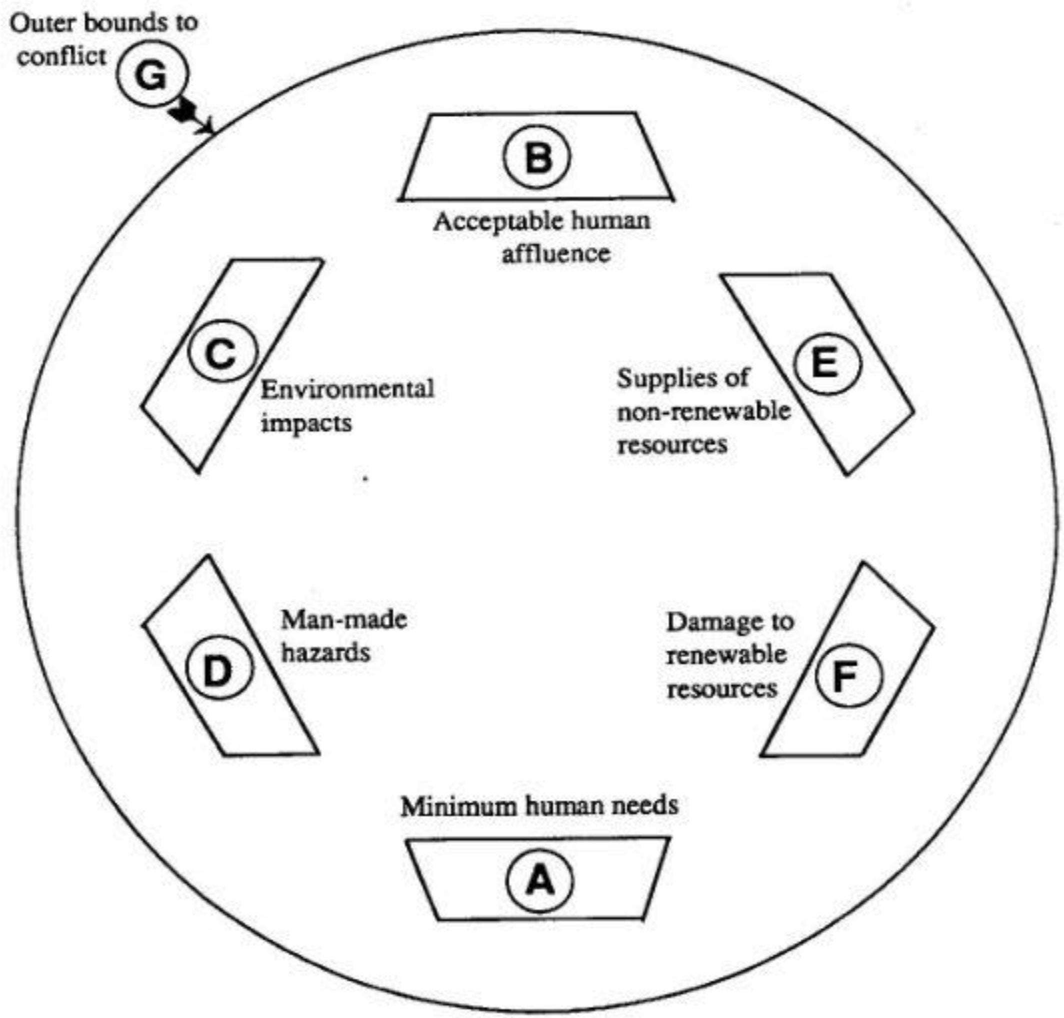
In a world where people live and work in such widely different ways, it is not easy to generalize about human requirements. Yet people do seem to have certain felt needs in common, even though these vary greatly in expression with culture, tradition, climate, availability of modern communication, degree of industrialization, and time. These common requirements are:

- Basic human needs ("enough" food, shelter, health, education, employment, and security for a person).
- A sense of the dignity of being human.
- A sense of becoming (a chance to achieve a better life).
- A sense of justice and equity.
- A sense of achievement, related to something worth achieving.
- A sense of solidarity, of belonging to a worthy group and of participation in decisions that affect the group's, and one's own, destiny.

Large numbers of people in dozens of countries now understand that, left to its "inner logic" without societal policy-making, science-and-technology won't pay enough attention to such human needs and purposes. We have created the capacity to end it all or, in the alternative, to make the human adventure wonderfully endless. We can make the world

Fig.1

The Emerging Ethic of Ecology



uninhabitable, or make it super-habitable. Genetic magic may even enable us to mold ourselves and especially our progeny — if we can figure out who we want to be.

The one thing we cannot do, in the Age of Information, is to keep people quiet about all this, by keeping them ignorant. The spread of mass education brings in its train a global 'fairness revolution', an aggrieved demand for more participation to make sure the wonders of science and technology are widely and equitably shared.

During the next 300 years, barring unnatural (because man-made) catastrophes, we the people will be taking scientific discovery and technological innovation off "automatic pilot" and steering them toward the fulfillment of human aspirations; beginning by not ending with what labor pioneer Samuel Gompers called the most basic needs of all — bread, work and peace.

The "internal logic" of the Scientific Revolution is now under serious question, and its awesome power may never be the same. If science is the religion of modern governance, a new kind of Reformation is seemingly at hand.

VIII.

The original Reformation coincided with the invention of printing, which enabled Martin Luther's local action (fastening 93 theses "for the purpose of eliciting the truth" to the door of Frederick's Castle Church in Wittenburg on October 31, 1517) to be copied and circulated far and wide, provoking a public controversy from which the authority of the medieval Church could not recover. The new Reformation will also be powered by information technology; computers hitched to electronic telecommunications.

In Martin Luther's time, indulgences and other forms of corruption had already polluted the social fabric and weakened the authority of the medieval Church over secular affairs. In our time the social fallout of science-and-technology — the dangers of nuclear explosive power, the moral dilemmas inherent in biotechnology, the potentials of unprecedented climate change, the ambiguous miracles of informatics — has been advertised worldwide, and is inducing global second thoughts. Meanwhile American politics and public administration, which ought to be focussing on these larger, urgent, global issues, are mired in self-indulgence and no little corruption.

What theses, composed on computers, transmitted by telecommunication, shall we in our time now tack up on our electronic bulletin board? There is no room left in this article for 95 of them. But an illustrative half dozen will be sufficient to suggest the new sense of direction.

1. <u>What science leads to is a primary business of public administration</u>. That means public administrators have to try to learn the essence of new scientific discoveries and ponder the range of new technologies they make possible. These learnings (which, to put it mildly, have not been at the core of education for public administration), must also be timely, so the institutions and processes and codes of conduct can be invented <u>while</u> the scientists and engineers are converting their ideas into hardware, not after the deed is done. The alternative is what Arthur C. Clarke, that perceptive scientist and writer of science fiction, calls "technoporn . . . gleaming weaponry and beautiful explosions".

2. <u>For the '90s and beyond, public administration will be the art of making creative interconnections</u>. All real-world problems are interdisciplinary, interprofessional, and international. Policy analysts and policy managers must daily combine the rigors of varied disciplines, the insights of multiple professions, the workways of diverse cultures. But remember that a committee of narrow thinkers doesn't produce integrative outcomes. The best interdisciplinary instrument is still the individual human mind.

3. Public administration is not one more discipline, to be defied by a particular method of analysis. Nor is it a profession struggling for recognition in a crowd of specialists, in the tradition of law and medicine and business management. It is the public action, the public responsibility component of every discipline and every profession. Public administration focuses on how the general management of any society uses expert knowledge and specialized methods to make something different happen. So it must be centrally concerned with the politics of value and the values of politics.

4. People can agree on next steps to be taken together if they carefully avoid trying to agree on why they are agreeing. In the administration of complex human affairs, let's not bet on "management by objectives". Let's bet instead on management despite diverse objectives.

5. In the management of complexity made necessary by science and technology, open systems work best. Consulting widely can be costly, can create delays, cause frustration, generate opposition that can be avoided if the objectors are kept outside the "need to know" circle. But in our changing information environment more openness much more often than not make for better policy, especially when it brings into consultation people (or groups, or nations) who will have to agree on a plan if their cooperation is needed to carry it into action. In living memory, our most spectacular mistakes in public policy and administration have come from pulling too tight the "need to know" drawstring. Usually two heads are better than one, three heads are better than two and so on for quite a number of heads before the *n*th addition to the circle of knowledge-based responsibility adds nothing more to wisdom.

6. Above all, let's put behind us the idea that the politics and administration of human endeavors are some kind of science. (I still remember a moment of heated faculty debate when at the Maxwell School , 30 years ago, a distinguished economist was defending his intellectual turf. "At least," he argued, "economics is the hardest of the soft sciences!") The management of relations among people, and among peoples, has always been more art than science. That's why, more than two millennia before Newton and the Scientific Method, Aristotle in his Politics and Lao Tsu in the Tao Te Ching were already giving advice that is helpful today in the administration of complexity. Like Lao Tsu's sage, the wise public administrator:

> . . . never tries to store things up.
> The more he does for others, the more he has.
> The more he gives to others, the greater his abundance.

This is not scientific. It's not even rational. It is merely wisdom.

Notes

Isaac Newton's *Principia* was first published in Latin in the summer of 1687 as *Philosophiae Naturalis Principia Mathematica*. It was not until 42 years later, in 1729, that it was first published in English as *Mathematical Principles of Natural Philosophy*.

I am indebted to my colleague Donald Geesaman, a theoretical physicist who now serves as Professor of Public Affairs in the University of Minnesota's Hubert H. Humphrey Institute of Public Affairs, for the metaphor suggesting that the modern state invokes science in something like the way the medieval state invoked the Church to legitimize its power and justify its acts.

My discussion of scientific breakthroughs leading to new theories of society can be traced to work by Professor Ralph L. Ketcham of the Maxwell Graduate School of Citizenship and Public Affairs, Syracuse University. This and the material on the "ecological ethic" were developed for Philadelphia's Bicentennial Era Program (1976-

1987), "A Declaration of INTERdependence." For a fuller context, see Harlan Cleveland, *The Third Try at World Order*, (Aspen Institute for Humanistic Studies, New York, 1977.)

The framers of the U.S. Constitution consciously derived some of their metaphors from Newton. In a 1792 essay on "Spirit of Governments", James Madison said of Newton and Locke that they "established immortal systems — the one in matter, the other in minds." (*The Papers of James Madison*, Vol. 14, p.233) Thomas Jefferson alluded to Newton's calculations on the pendulum when he drew up his observations on coinage, weights and measures around March, 1784. (Boyd, *Papers of Jefferson*, VII, pp. 173-174). In a 1785 letter to James Monroe, Madison was on the same wavelength: "With regard to the regulation of weights & measures, wd. it not be highly expedient as well as honorable to the federal administration, to pursue the hint which has been suggested by ingenious & philosophical men, to wit, that the standard of measure sd. be first fixed by the length of a pendulum vibrating seconds at the Equator or any given latitude — & that the Standard of Weight sd. be a cubical piece of gold or other homogenous body of dimensions fixed by the standard meassure." The editor of the Madison papers says in a footnote that Isaac Newton was one of the "ingenious & philosophical men" referred to by Madison. (*The Papers of James Madison*, Vol. 8, pp.272-273).

The quotation about "global hormones" is from Lewis Thomas, *Lives of a Cell*, (Bantam Books, New York, 1975, p.48).

The implications of considering information as a resource in itself are spelled out in an earlier article of mine, The Twilight of Hierarchy: Speculations on the Global Information Society, *Public Administration Review*, Vol. 25, Jan/Feb 1985, pp.185-195.

For fuller discussion of "the new ambivalent mood — still mesmerized by science, but newly wary of technology," see Harlan Cleveland, *The Knowledge Executive: Leadership in an Information Society*, (E.P. Dutton, New York, 1985), especially Chapters 8, ("The Social Fallout of Knowledge" pp. 125-144) and 9 ("A Harness for Technology" pp. 145-158).

The summary of human requirements derives from an Aspen Institute seminar during the summer of 1977 in which 45 people from eight countries and 33 professions tried to figure out what was wrong with the "growth ethic" and what its successor might be. Note that, although obviously influenced by Abraham Maslow's famous hierarchy of needs and values, the categories of "common requirements" are presented not as a linear progression but as universals shared in differing degrees by all human beings (Harlan Cleveland and Thomas W. Wilson, Jr., *Humangrowth: An Essay on Growth, Values and the Quality of Life*, Aspen Institute for Humanistic Studies, New York, 1978). See also John and Magda Cordell McHale, *Human Requirements, Supply Levels and Outer Bounds*, (Aspen Institute Program in International Affairs, Princeton, N.J., 1975) and *Basic Human Needs*, (Transaction Books, New Brunswick, N.J., 1978).

That arresting new word "technoporn" was put forward by Arthur C. Clarke in "Star Peace", his acceptance speech on receiving the Charles A. Lindbergh Award in Paris, May 20, 1987.

Diligent readers of my writings on management and leadership will find old friends among the "theses" at the end of this article. (It isn't plagiarism to steal from yourself.) An update on my way of thinking about public affairs and administration, in the context of an "information society" can be found in *The Knowledge Executive, op.cit.*

Non-Equilibrium Economics: Alternative paradigms and technology policy

by

Calestous Juma

Introduction

Africa is currently undergoing a major economic and ecological crisis. The traditional socio-economic structures are being rapidly dissipated. The conventional approaches to the analysis of the African crisis have failed to adequately explain the situation or to offer any viable policy options for the continent. This failure is partly attributable to the extensive dependence on Newtonian metaphors and other mechanistic views for the analysis of economic and social problems. These Newtonian metaphors emphasize the equilibrium idea and do not take into account time and irreversibility as significant factors in socio-economic evolution. The resulting policy responses are analogues of classical mechanics and most of the proposed solutions are based on reductionism and static Weberian institutional mechanisms.[1]

What is needed is an analytical framework that recognizes the fact that economies are open systems which evolve and are in constant re-organization through the introduction of new information and technology. This non-equilibrium view would also take into account non-linear economic behavior, major bifurcations resulting from the introduction of new knowledge and the application of science and technology in development. This approach would lead to alternative policies which are not preoccupied with the restoration of economic equilibrium, but which instead emphasize the accumulation of technological capability, organizational flexibility, social experimentation, recognition of diversity and autonomy. This view requires a radical departure from the Newtonian world view (and its Baconian and Cartesian underpinnings).

1. Newtonian Mechanics and Economic Thought

Concern over the mechanistic content of economics and the purging of its 'organic' content goes back to the turn of the last century. Veblen once asked: "Why is Economics not an Evolutionary Science?"[2] There are several reasons for this. Firstly, evolutionary thought was still embryonic at the time economic thought was being consolidated. Charles Darwin came onto the scene a century after Adam Smith.[3] Research in the biological sciences was largely devoted to classification rather than measurement and analysis. But even more important were the efforts made in the 18th and 19th centuries to adopt the Baconian, Cartesian and Newtonian world views in economic analysis.

The history of science may be hitherto summed up as a relentless search for what William James once called "irreducible and stubborn facts".[4] From the time of the ancient Greek civilization down to the Middle Ages, the search for irreducible and stubborn facts became a major subject of inquiry. This was brought to a head by Galileo, whose tradition was continued by Newton. When Galileo insisted that scientists should restrict themselves to those vital properties of material bodies which could be expressed in shapes, numbers and movements, he was preparing the ground for the coming era of abstractions. And with

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[1] See Calestous Juma, *Evolutionary Technological Change*; Clark and Juma, *Long Run Economics*.

[2] This was the title of his classic 1898 article. See Hamilton, *Newtonian Classicism and Darwinian Institutionalism*, for a comparison between Newtonian and Darwinian approaches to economics.

[3] Even the Darwinian approach had strong Newtonian tendencies as explained in Brooks and Wiley, *Evolution as Entropy*.

[4] William James, quoted in Whitehead, *Science and the Modern World*, p.3

the advent of Newtonian mechanics, biological and evolutionary ideas (most of which were too dynamic to be subjected to the limited quantitative methodology of the day) were pushed to the periphery of mainstream science.[1]

The 17th century was the golden era of abstractions. Indeed, abstractions are a powerful analytical tool. By highlighting the essentials, they improve understanding of social and physical processes and help to rid society of numerous fallacies and misconceptions. But they give little attention to the rest. Insofar as the excluded aspects are significant, these abstractions may not necessarily reflect the totality from which they originated. This can easily lead to narrow-mindedness. As Whitehead says, the great thinkers who consolidated modern scientific thought "applied the 17th century group of scientific abstractions to the analysis of the unbounded universe. Their triumph....was overwhelming; whatever did not fit into their scheme was ignored, derided, disbelieved.".[2]

Abstractions are usually instantaneous configurations of matter expressed in the context of time and space, appearing in simple location. Whitehead argues that this simple location has led to the error of mistaking the abstract for the concrete, the"fallacy of misplaced concreteness".[3] As the simple location has therefore "no reference to any other times, past or future, it immediately follows that nature within any period does not refer to nature within any other period."[4] Reality is therefore deprived of its historical context.

This is the 17th-century tradition to which economists aspired; the tradition of hard science. Post-Smithian economics relied increasingly on abstraction; mathematicians endeavored to make the discipline an exact science. This process reached a significant peak with the publication in 1874 of Walras' *Elements of Pure Economics* whose general equilibrium theory has strong mechanical underpinnings. To Walras, "the pure theory of economics or the theory of exchange and value in exchange" was simply a "physio-mathematical science like mechanics or hydrodynamics".[5] The history of conventional economic thought from Walras to modern times can be largely described as an elaborate footnote on Newton: the discipline, with its equations and analytical tools, is a metaphor for Newtonian mechanics.

The need to make economics an exact science was a strong motivating force during the period. He says that it is "perfectly clear that economics, like astronomy and mechanics, is both an empirical and rational science".[6] Walras complained that France produced mathematicians with no knowledge of economics and cultivated men of letters devoid of any notion of mathematics. This, in his view, led to the flourishing of bad mathematicians and bad pure economics. He said the 20th century would need to entrust the social sciences to

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[1] The Newtonian model was applied across the board from science to politics and ethics. Newton's Principia, in the 300 years since its publication, has influenced academic thought more than any other single work. A detailed account of how the Cartesian-Newtonian paradigm has adversely influenced the sciences in general, and medicine in particular, is given in Capra, *The Turning Point*. Its application to the constitutional monarchy is underscored by Desaguliers in these verses (as quoted in Koyré, *Galilean Studies*:

"Like Ministers attending ev'ry Glance
Six Worlds sweep round his Throne in Mystick Dance.
He turns their Motion from his Devious Course,
And bends their Orbits by Attractive Force;
His Pow'r coerc'd by Laws, still leave them free,
Directs, but not destroys, their Liberty;...."

[2] Whitehead, *Science and the World*, p.74.

[3] *Ibid.*, p.65

[4] *Ibid.*, p.64

[5] Walras, *Elements of Pure Economics*, p.71

[6] *Ibid.*, p.47

men of general culture initiated into inductive and deductive thinking and familiar with reason and experience. "Then mathematical economics will rank with the mathematical sciences of astronomy and mechanics; and in that way justice will have been done to our work."[1]

But the very discipline that was setting the pace for economics started to change its course in the last century, leading to the new physics. Advances in physics have shown that in the sub-atomic world, there are no irreducible and stubborn facts but relationships, no isolated entities but systems.[2] It can therefore be argued that conventional economics is well ahead of the other social sciences, but advancing in a misleading direction: while even the pace-setter, physics, has changed course, most economists still adhere to the old ways of thinking. Georgescu-Roegen says that "by the time Jevons and Walras began laying the cornerstones of modern economics, a spectacular revolution in physics had already brought down the mechanistic dogma both in the natural sciences and in philosophy. And the curious fact is that none of the architects of 'the mechanics of utility and self-interest' and even none of the latter-day model builders seem to have been aware at any time of this downfall." [3]

Other sciences are also changing course. As Veblen said, if "economics is to follow the lead or the analogy of other sciences.... the way is plain so far as the general direction in which the move will be made".[4] This is the evolutionary route. This route, however, was not taken.[5]Instead, evolutionary concepts in the post Marshallian period sought refuge in other theoretical camps.

Early economic studies of the Third World countries were largely influenced by mechanistic thinking. This is partly because of the influence of both the concept of comparative advantage and that of the "dependency school".[6] These two schools of thought retain strong mechanistic elements. The concept of comparative advantage assumes a world which is reversible and one where the values of each product are (reducible to quantifiable units which are) known in advance and their effects on the balance of trade can be established *a priori*.

The international economic scene is viewed through the Heckscher-Ohlin model as a balanced system in which countries producing labor-intensive goods can mutually benefit from trade with those producing capital-intensive goods. This reductionist model assumes uniformity in technology and consumption patterns. It only allows for variations in factor

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1 *Ibid.*, p.48

2 There is a parallel between this view and emerging concepts in development studies. There seems to be a shift towards the recognition of the role of small organizations or economic units that rely on networking and information exchange s viable agents of the developmental process. This view is, however, still nascent.

3 Entropy and the Economic Process, pp.2-3.

4 Veblen, Why is Economics not Evolutionary? p.388

5 Much of Smith's equilibrium ideas, laws of motion and scientific objectivity are drawn from Newtonian physics. The economic sphere was a microcosm of the celestial arena; forces of supply and demand, guided by the invisible hand, would generate a balance, as market forces gravitated in the right direction. Newtonian concepts can also be traced in the economic formulation of human welfare. The ideal social welfare balance, like that of Newton's celestial objects, could be realized through some form of Pareto optimality. The reification of the Newtonian model has left the discipline a set of analytical tools which cannot adequately deal with the complex realities of economic evolution.

6 This view is represented in Merhav, *Technological Dependence*; Frank, *Latin America Underdevelopment*; UNCTAD, *Guidelines for the Study of Technology Transfer*; and Amin, *Accumulation on a World Scale*.

endowment. But the factor endowments are reducible to reversible and homogeneous units which can be analyzed using the production function.

This however, does not mean that labor and capital do not play a part in the generation and spread of production technologies. What is important is not the static choice of technique but the dynamic articulation of technologies within the socio-economic system. This is an adaptive process that involves learning and the constant generation of information and knowledge. It is this learning aspect that makes technological change an evolutionary process which defies any static analysis.

The diffusion of technology is still largely analyzed using aggregate models. These models use the standard logic curves which only reflect the successful innovations and ignore the numerous trials that are made during the articulation of a particular technology through the social and economic system. Indeed, the diffusion models have a strong element of linearity and assume the existence of a smooth Newtonian trajectory for each new piece of technology. This view also assumes that the initial conditions are known and therefore that the behavior of the technology during the diffusion process can be understood.

Although this is a simplification of the theory, it captures the mechanistic content of its central themes. From these themes have sprung a series of theories of the transfer of technology to the developing countries. These theories assumed that technological systems were given units whose values were known or reducible to a few variables such as factor proportions. All that was needed was knowledge of the income levels and labor coefficients. With this it was therefore possible to determine the type of technology that could be adopted by the developing countries.[1] This is the heritage that has come to shape the analysis of economic and technological change in Africa. The Cartesian labor-capital dichotomy made it difficult for economic theory to accord technological change a significant role in economic development; it was treated as exogenous to the process.

As a result of these philosophical underpinnings, the economic policies of most African countries have failed to recognize the role played in economic change by the introduction of technology and information. Not only do their policies not reflect the imperatives of economic transition but they also emphasize relatively unimportant policy instruments which are aimed at restoring economic equilibria. Institutions are used to keep the economic system in some kind of equilibrium, and in some cases they are eliminated altogether because they are assumed to hinder the efficient operation of the market forces: they are conceived of as sources of friction and distortions in the economic sphere.

> "It is interesting to note how closely the modern tradition in economics echoes [the] mechanistic framework set out most clearly by the Austrian School. Economic systems are conceived of in terms of *units of production* (firms) and *units of consumption* (households) exchanging commodities and factor services in *markets* at *prices* which reflect the forces of supply and demand. Markets always are predisposed to clear since competition among buyers and sellers ensures that prices will *equilibrate* at precisely the point at which there is no excess deficiency of goods and services in the market place" [2]

It is difficult to understand how metaphors based on static and reductionist ideas could be a suitable basis for analyzing dynamic and complex systems. We propose to offer an alternative view that is based on the current understanding of evolving complex systems that undergo re-organization through the introduction of new knowledge and technology. Economic change is viewed as a learning process in which societies adapt to constantly changing conditions; we assume uncertainty and non-equilibrium reality.

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1 For a critique of factor proportion analysis of developing countries, see Eckhaus, The Factor Proportions Problems.

2 Clark and Juma, Long Run Economics.

2. The Evolution of Non-Newtonian Economics

Classical economists re-organized the dichotomy of static and dynamic systems, although they were influenced more by mechanical dynamics than by organic evolution. It is in this context that the dynamics of Mill and Smith can be understood. Smith recognized the evolution of society through complexity and differentiation, as exemplified by his assessment of the division of labor. But he drew a distinction between functional differentiation in zoological and social systems by stressing that unlike animals, human beings had specific attributes which enabled the division of labor to emerge; the ability to truck, barter and exchange. These abilities could be brought into a common stock "where every man may purchase whatever part of the produce of the other men's talent he has occasion for".[1]

The first major attempt to cast technology in an evolutionary context was made by Marx. Technology, according to Marx, evolves from crude designs to more refined systems that benefit from scientific disciplines:

> The power loom was at first made... of wood; in its improved modern form it is made of iron... It is only after considerable development of the sciences of mechanics, and an accumulation of practical experience that, the form of a machine becomes settled entirely in accordance with mechanical principles, and emancipated from the traditional form of the tool from which it emerged. [2]

This occurs in a mutually-reinforcing socio-economic environment.[3] In this interactive process, the role of individuals adds only a little to the broader evolution.[4]

Marx equated the development of technology to that of biological organs. "Darwin has directed attention to the history of natural technology, i..e the formation of the organs of plants and animals which serve as the instruments of production for sustaining their life. Does not the history of the productive organs of man in society, or organs that are the material basis of ever particular organization, deserve equal attention?"[5] As the tools evolve, they are adapted to the requirements of particular applications and professions.

> "In Birmingham alone 500 varieties of hammer are produced, and not only is each one adapted to a particular process, but several varieties often serve exclusively for different operations in the same process. The manufacturing period simplifies, improves and multiplies the implements of labor by adapting them to the specific functions of each kind of worker,"[6]

This functional differentiation forms one of the material conditions for the existence

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[1] Smith, *The Wealth of Nations*, p.121. "The strength of the mastiff is not... supported by either the swiftness of the greyhound, or by the sagacity of the spaniel, or by the docility of the shepherd's dog. The effects of those different geniuses and talents... cannot be brought into a common stock, and do not... contribute to the better accommodation and conveniency of the species," *Ibid.*, p.21

[2] Marx, *Capital*, Vol 1, p.505.

[3] "Social relations are closely bound up with productive forces. In acquiring new productive forces men change their mode of production; and in changing their mode of production, in the changing the way of earning their living, they change all their social relations. The handmill gives a society with the feudal lord; the steam-mill, society with the industrial capitalist," Marx, *Poverty of Philosophy*, p.102.

[4] "A critical study of technology would show how little any of the inventions of the 18th century are the work of a single individual." Marx, *Capital*, Vol 1. p.493.

[5] *Ibid.* Marx laments the absence of such a book. It still does not exist. Marx attempted to write such a history, which is still locked away in unpublished notes. See Colman, Short Communications, pp. 234-235, for a list of the unpublished notebooks, dating mainly from 1863. Recent publications of Marx's work on technology are available in German by Müller, *Karl Marx*, and Wilkelmann, *Karl Marx*.

[6] Marx, *Capital*, Vol 1. pp.460-461.

of machinery. Here we see Darwin's law of variation applied to technical change.

> "As long as the same part has to perform diversified work, we can perhaps see why it should remain variable, that is, why natural selection should not have preserved or rejected each little deviation of form so carefully as when the part has to serve for some one special purpose. In the same way that a knife which has to cut all sorts of things may be of almost any shape; whilst a tool for some particular purpose must be of some particular shape."[1]

Marx recognized that technical change continued long after the machinery had been installed, a fact that underscores the evolutionary nature of technological progress. He paid particular attention to the role of working experience, or the accumulation of knowledge, and anticipated the modern studies of firm-level technical change in the capital goods sector.

> "When machinery is first introduced... new methods of reproducing it more cheaply follow blow by blow, and so do improvements which relate not only to individual parts and details of the machine, but also to its whole construction." [2]

Marx's evolutionary ideas were overshadowed by his appeal for revolutionary social change and therefore did not have any major influence on mainstream economics. It was Marshall who first attempted to bring these ideas into the mainstream of economic thought.[3] To Marshall, the "Mecca of economics lies in economic biology rather than economic dynamics."[4] He argued that economics was like biology because they both dealt with "a matter, of which the inner nature and constitution , as well as the outer form, are constantly changing".[5] For Marshall, the subject matter of economics was "human beings who are impelled, for good or for evil, to change and progress". [6] But not for all human beings because "economics is a study of... particular nations, of particular social strata; and it is only indirectly concerned with the lives of men of exceptional genius or exceptional wickedness". [7]

Although Marshall advocated the use of biological concepts, his own work paid only token allegiance to the approach, a mere pilgrimage to the Mecca of economics. Much of his Principles of Economics is non-evolutionary except for the sections which deal with industrial organization and the division of labor. Marshall draws from the concepts of survival of the fittest and the physiological views of human behavior. He sees large scale industries as trees of the forest which grow, compete for light and water, lose vitality, grow old, and die; except for "vast joint-stock companies, which often stagnate, and do not readily die".[8]

Marshall's evolutionary views differed remarkably from Marx's because of his appeal to Darwinian gradualism: "Economic evolution is gradual. Its progress is sometimes arrested or reversed by political catastrophes: but is forward movements are never sudden; for even in the Western world and in Japan it is based on habit, partly conscious, partly unconscious,".[9] But like Marx, he admits that individuals add only little to the cumulative changes which have been in the making long before them. Thus

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[1] Charles Darwin, *Origin of Species*, quoted in Ibid, p.461.

[2] *Ibid.*, p.528.

[3] For a review of Marshall's assertion that economics was a branch of biology, see Hirshleifer, Economics from a Biological Viewpoint, and Hirshleifer, Evolutionary Models in Law where he has also tried to blend economics, law and evolutionary concepts. For an assessment of the use of economic models in ecology, see Rapport, *et al*, Economic Models in Ecology.

[4] Marshall, *Principles of Economics*, p. xii.

[5] *Ibid.* p.637

[6] *Ibid.*, p. xiii.

[7] *Ibid.*, p.697.

[8] *Ibid.*, p.263.

[9] *Ibid.*, p. xi.

"...an inventor, or an organizer, or a financial genius may seem to have modified the economic structure of a people almost at a stroke; yet the part of his influence which has not been merely superficial and transitory, is found on inquiry to have done little more than bring to a head a broad constructive movement which has long been in preparation,".[1]

Marshall visualized some form of equilibrium in the growth of firms. He states that "a business firm grows and attains greater strength, and afterwards perhaps stagnated and decays; and at the turning point there is a balancing or equilibrium pf the forces of life and decay..."[2] But although such balances appear dynamic, Marshall did not abandon the Cartesian-Newtonian world view. For the foundations of economics must "give a relatively large place to mechanical analogies".[3] The fragmentary statics were seen as a temporary feature. However, he offered an economic methodology under which mechanical analogies would be used in the early stages of economic evolution and biological explanations would take over in later stages.

"There is a fairly close analogy between the early stages of economic reasoning and the devices of physical statics... I think that in the later stages of economics better analogies are to be got from biology rather than from physics, and, consequently, that economic reasoning should start on methods analogous with those of physical statics, and should gradually become more biological in tone,".[4]

Marshall insisted on using mechanical analogies and mathematical abstractions. mathematics was only useful to economics if it could throw "a bright light on some small part of the great economic movement rather than at representing its endless complexities."[5] As a result, the subject matter would have to be reduced to steady-state entities that validate the use of mathematics. His tone was Newtonian. Like celestial bodies, parts change while the population remains stable; businesses rise and fall while firm population remains the same; grain prices fluctuate with every harvest but the average value of the grain remains stable.

To Marshall, the growing command of mankind over nature changed the character and magnitude of economic and social forces in a Newtonian way:

"Our planetary system happen... to be a stable equilibrium; but a little change in circumstance might make it unstable; might for instance, after a time cause one of the planets to shoot away from the sun in a very long ellipse, and another to fall into it."[6]

The law of supply and demand also takes, at an early stage, a Newtonian outlook:

"In the earlier stages of economics, we think of demand and supply as crude forces pressing against one another, and tending towards a mechanical equilibrium; but in the later stages, the... equilibrium is conceived not as between crude mechanical forces, but as between the organic forces of life and decay."[7]

Marshall was committed to the mechanical thinking of the day despite his appeal to biological analogies. All life is reducible to matter, the 'hard stuff' that all things are supposedly made of. This could be understood through mechanical analogies. And since society is not an ordinary combination of inanimate material, we have to revert to an organic view of economic activity. The ambivalence is reflected in his analysis of competition, leading to some confusion over perfect and imperfect competition. His approach was later re-orientated by the neo-classical school, especially with the formulations of mo-

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[1] *Ibid.*, p. xii.

[2] *Ibid.*, p.269

[3] *Ibid.*, p.12

[4] Marshall, Mechanical and Biological Analogies, p.314

[5] *Ibid.*, p.313

[6] *Ibid.*, p.317

[7] Ibid., p 318.

nopolistic competition and imperfect competition.[1] It is instructive that his biological views have been a subject of ridicule by neo-classical economists, for example by Samuelson:

> "All this prattle about the biological method in economics — and the last decades' genuine progress in biology through the techniques of physics has confirmed my dictum... that talk about a unique biological method does represent prattle — cannot change this fact: any price taker who can sell more at the going price than he is now selling and who has falling marginal costs will not be in equilibrium. Talk of birds and bees, giant trees in the forest, and declining entrepreneurial dynasties is all very well, but why blink at such an elementary point?"[2]

Marshall's biological notions remained underdeveloped as neo-classical thought took root.

Although post-Marshallian economic thought was dominated by mechanistic ideas, efforts were made to inject some dynamic elements into its content.[3] One of these areas was market competition. It was viewed in conventional economics as analogous with Newtonian motion where resources "gravitated" towards their optimal utility and prices were "forced" to the lowest possible levels sustainable in the long run. Competition therefore guaranteed order and stability in the market just as gravitation did among Newtonian bodies.[4] This view did not adequately account for the competitive behavior of firms. Economic theory was bedevilled with the paradoxical concepts of monopoly and perfect competition; "both are situations in which the possibility of any competitive behavior has been ruled out by definition".[5]

Chamberlin attempted to re-orientate economic theory by introducing dynamic concepts. His analysis sought to synthesize monopoly and competition ideas in a way that was akin to chemical processes.[6] Chemical synthesis requires continuous movement and change, thereby taking an evolutionary outlook under dynamic and static characteristics are clearly distinguished. Moreover, the dominant role of continuous product differentiation and the wide range of product possibilities suggest an implicit evolutionary content.

Although product variation plays a significant role in Chamberlin's model, it is not clear whether technology was to be held constant or not. But since he stressed product variation, it is reasonable to assume that innovation would play a significant role in the process. Indeed, he subsequently admitted that an entrepreneur would need to innovate to break away from the established order of things.

> "The appearance on the market of every new product creates pressure in some degree on the markets for others, and when products are variable and determined by profit maximization some of this pressure is bound to be exerted on quality in order to maintain prices which people can afford to pay. Thus, in a world whose technology is constantly creating new products, it should not be surprising to find that a part of the whole process is the deterioration of other products in order to make room for the new ones at the mass market level where the population is concentrated.".[7]

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[1] See Chamberlin, *Theory of Monopolistic Competition* and Robinson, *Economics of Imperfect Competition.*

[2] Samuelson, The Monopolistic Competition, p.112.

[3] See Spengler, Evolutionism in American Economics, for a review of evolutionary thought in American economics since 1776.

[4] McNulty, Economic Theory and Meaning of Competition, has extended the physical analogy to equate the concept of perfect competition to a perfect vacuum; "not an ordering force" but rather an assumed "state of affairs", *Ibid*, p.643.

[5] *Ibid.*, p.641.

[6] Chamberlin, *Monopolistic Competition*, p.3

[7] Chamberlin, Product as Variable, p.131

Technical change therefore continues to unfold as firms adjust to emerging competitive conditions in the market environment.

Despite these dynamic aspects, Chamberlin did not seek to present his theory in an explicitly evolutionary way. This was left to Alchian, who sought to replace the notion of profit maximization with the biological concept of natural selection. "The suggested approach embodies the principles of biological evolution and natural selection by interpreting the economic system as an adoptive mechanism which chooses among exploratory actions generated by the adaptive pursuit of 'success' or 'profit'.[1] Competitive behavior among firms, he argued, was not determined by the motive of profit maximization, but by "adaptive, imitative, and trial-and-error" behavior in the search for profits.

Success was influenced and reinforced by previous success, not motivation. The fact that successful firms were still in the market was not a result of their profit maximizing behavior but because others had been eliminated. The situation is clearly Darwinian: "Those who realize positive profits are the survivors; those who suffer losses disappear."[2] He rejects the efficacy of the entrepreneur because in a world of fools there would still be profits. "Also, the greater the uncertainties of the world, the greater is the possibility that profits would go to venturesome and lucky rather than to logical, careful, fact-gathering individuals".[3] Although Alchian gives a detailed assessment of the behavior of firms in a competitive environment, he does not offer a convincing account of the role of technical change in economic natural selection. Part of the problem results from excessive emphasis on imitative behavior to which much of the innovation is attributed. "Adaptive behavior via imitation and venturesome innovation enlarges the model. Imperfect imitators provide opportunity for innovation and the survival criterion of the economy determines the successful, possibly because imperfect, imitators."[4]

But those who pioneer in innovating do so in response to changing market conditions. "Innovation is provided also by conscious willful action, whatever the ultimate motivation may be, since drastic action is motivated by the hope of greater success as well as the desire to avoid impending failure."[5] This view ignores conditions under which innovation becomes a critical competitive tool; it sets in motion the imperatives for its constant improvement.

As in neo-classical approaches, Alchian treats technical change as exogenous to economic evolution. It is merely brought into play for purposes of adaptation to the changing market environment but does not necessarily shape those conditions. But in spite of these shortcomings, Alchian provides a useful starting point for incorporating innovation into the economic natural selection process. Alchian did not seek to reframe all economic theory into an evolutionary outlook. He restricted his analysis to firm behavior, especially on the irrelevance of the notion of profit maximization.

Institutional economics, or institutionalism, provided one of the earliest bases for evolutionary concepts. Institutionalism was not itself a coherent package of analytical tools, but a diverse collection of critical ideas built on a theoretical and methodological

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[1] Alchian, Uncertainty, Evolution and Economic Theory, .211. For an enlargement of Alchian's approach, see Enke, On Maximizing Profits. Penrose, Biological Analogies in the Theory of the Firm, had provided a critique of Alchian's model, emphasizing the purposive nature of the profit motive and the dangers of relying on biological metaphors.

[2] *Ibid.*, p.213.

[3] *Ibid.*

[4] Ibid., p.219.

[5] Ibid.

rejection of conventional economics. It revolved around Veblen, Mitchell, and Commons.[1] They were dissatisfied with the neo-classical preoccupation with abstractions, demanded the integration of other social sciences into economic thought, and rejected the casual empiricism of conventional economics.

Veblen argued that economic activity evolved in an unfolding sequence, consistent with the close-knit body of theory required for any evolutionary science. But conventional economics had remained at the stage where "the natural sciences passed through some time back".[2] The tools of economic analysis were still taxonomic. Veblen sought to reformulate the contextual setting of economics. Industry and technology are the motivating power behind this process.

> "The active material in which the economic process goes on it the human material of the industrial community. For the purpose of economic science the process of cumulative change that is to be accounted for is the sequence of change in the methods of doing things — the method of dealing with the material means of life,".[3]

Veblen was writing at the turn of the century, when the role of technological change in economic evolution had become apparent, but was largely unexplained. To him, everyone was intractably trapped in the evolutionary sweep of technological advancement. "Under the stress of modern technological exigencies, men's everyday habits of thought are falling into the lines that in the sciences constitute the evolutionary method; and knowledge which proceeds on a higher, more archaic plane is becoming alien and meaningless to them. The social and political sciences must follow the drift, for they are already caught in it,".[4] Veblen placed his evolutionary conception in an endogenous institutional context: "From what has been said it appears that an evolutionary economics must be the theory of a process of cultural growth as determined by the economic interest, a theory of a cumulative sequence of economic institutions stated in terms of the process itself".[5]

Veblen often suggested new directions for analysis but left them undeveloped. The role of technological change in the process of economic evolution therefore had to wait for the analysis of Schumpeter. He was a neo-classical thinker, yet his work contained both implicit and explicit evolutionary ideas. He was, admittedly, influenced by Walras and Marx,[6] but it is apparent that Schumpeter was also influenced by both static and dynamic economic theories. By locating economic transition in the broader context of social change, Schumpeter adopted an evolutionary model in which technological change and the efficacy of the entrepreneur as an innovative agent played the most significant roles. However, because of his Walrasian influence, he used the idea of equilibrium as a theoretical norm.

The Schumpeterian economic system carried strong evolutionary ideas. "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process."[7] The capitalist system can never be stationary. "And this evolutionary... process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change it alters the data of economic action; this fact is important and these changes (wars, revolutions and so on) often condition economic change, but they are not its prime movers. Nor is this evolutionary character due to a quasi-automatic in-

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[1] See Blaug, *Economic Theory*, p.678. Spengler, Evolutionism in American Economics, looks in detail at institutionalism since 1776. See also Boulding, A New Look at Institutionalism, for a critical assessment of institutional economics.

[2] Veblen, *op.cit.*, p 384.

[3] *Ibid.*

[4] *Ibid.* p.397.

[5] *Ibid.*, p.393.

[6] "Walras provided the foundation for his edifice, but Marx suggested to him the method for building on that foundation a structure that reflects his own vision." Smithies, Memorial, p.18

[7] Schumpeter, *Capitalism*, p.82

crease in population and capital or to the vagaries of monetary systems of which exactly the same thing holds true."[1] What then propels the evolutionary system of capitalism? "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the methods of production or transportation, the new market, the new forms of industrial organization that capitalist enterprise creates."[2] The changes "illustrate the same process of industrial mutation — if I may use that biological term — that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism."[3]

In his early work, Schumpeter analyzed not the process of evolution itself, but the dynamics which bring it about. "Not how the economic process developed historically to the state in which we actually find it, but the workings of its mechanism or organism at any given stage of development, is what we are to analyze."[4] The influence of Walras and Marx can be noted at this metaphorical level in his reference to the mechanism or organism of the economic process. He attempts to blend the two. Schumpeter follows Marx's cue by rejecting the hasty generalizations arising from the Darwinian "postulate that a nation, a civilization, or even the whole of mankind, must show some kind of uniform, unilinear development".[5] he also rejects the Newtonian view of society by asserting that historical "changes constitute neither a circular process nor pendulum movements about a centre."[6]

There is difference between Marx and Schumpeter which deserves mention. Marx started his analysis with socio-economic fluctuations and suggested that society would move towards equilibrium as classes disappear and institutions such as the state wither away. He thus collapsed into the Cartesian-Newtonian tradition. Schumpeter, on the other hand, started his analysis by assuming an equilibrium state but emphasized the manner in which the equilibrium was destabilized. Consequently, Marx was more interested in the abolition of capitalism while Schumpeter was interested in the sources and effects of instability in the economic system.

For Marx socialism would emerge from the collapse of capitalism while for Schumpeter it would result from the success of capitalism. Ironically, a Marxist position would lead to counter-evolutionary consequences as the sources of variability, competition, and selection are eliminated. This is a logical impossibility if the view that social systems are in constant flux is accepted.[7] There is a tendency in the Schumpeterian system for the situation to return to a near-equilibrium state. Investment opportunities shrink and the role of entrepreneurs becomes obsolete. Schumpeter's theory of economic developments emphasized the endogenous forces which bring about economic evolution. For economic development to occur, a society had to do more than just adapt to changing market conditions. If " the phenomenon that we call economic development is in practice simply founded upon the fact that the data change and that the economy continuously adapts itself to them, then we shall say that there is no economic development."[8]

In the Schumpeterian system, development is understood as "changes in economic life as are not forced upon it from without but arise by its own initiative, from within."[9] The

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[1] *Ibid.*, pp. 82-83

[2] *Ibid.*, p.83

[3] *Ibid.*

[4] Schumpeter, *Theory or Development*, p.10

[5] *Ibid.*, p.57

[6] *Ibid.*, p.58

[7] Marx largely used thermodynamic equilibrium as his normative reference.

[8] *Ibid.*, p.63

[9] *Ibid.*

transition is both cumulative and pre-conditional: "every concrete process of development finally rests upon preceding development... Every process of development creates the prerequisites for the following".[1]

His evolutionary theory of development transcends the notions of circular economic flows and the tendency towards general equilibrium.

> "It is spontaneous and discontinuous change in the channels of flow, disturbance of equilibrium, which forever alters and displaces the equilibrium state previously existing. Our theory of development is nothing but a treatment of this phenomenon and the processes incident to it."[2]

The changes in the circular flow and destabilization of equilibrium result in the sphere of industry and commerce (on the supply side) not in the area of "wants of the consumers of final products" (on the demand side). The shift is not, by definition, minor: it is one "which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps. Add successively as many mail coaches as you please, you will never get a railway thereby".[3]

Schumpeter emphasizes further the evolutionary view of economic change in his Business Cycles: "It is to physiology and zoology — and not to mechanics — that our science is indebted for an analogous distinction which is at the threshold of all clear thinking about economic matters".[4] He defines economic evolution as the "changes in the economic process brought about by innovation, together with all their effects, and the responses to them by the economic system".[5] Circular economic flows are viewed by Schumpeter as the circulation of blood in a dog, but the study of this circulation doesn't not show how dogs come to exist at all. "Obviously, we have here a different process before us, involving different facts and concepts such as selection or mutation or, generally, evolution." [6]

In his analysis, Schumpeter employs the same technique used by Marshall in which static abstractions form the theoretical norm:

> For our present argument we may thus visualize and economic process which merely reproduces itself at constant rates: a given population, not changing in either numbers or age distribution, organized for purposes of consumption in households and for purposes of production and trade in firms, lives and works in an unchanging physical and social (institutional) environment.[7]

By holding such factors constant, various neo-classical tools could be applied. The production function was one of them. According to Schumpeter, the production function "tells us all we need to know for purposes of economic analysis about the technological process of production".[8] Innovation, the central force in the Schumpeterian system, is defined simply "as the setting up of a new production function".[9] "But what dominates the picture of capitalist life and is more than anything else responsible for our impression of a prevalence of decreasing cost, causing disequilibria, cut-throat competition and so on, is innovation; the intrusion into the system of new productions functions which incessantly

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1 *Ibid.*, p.64

2 *Ibid.*

3 *Ibid.*

4 Schumpeter, *Business Cycles*, p.37

5 *Ibid.*,p.86

6 *Ibid.*,p.36

7 *Ibid.*,p.38

8 *Ibid.* See Atkinson and Stiglitz, A New View of Technological Change, for a critique of the production function approach. The article stresses local learning, which is a critical aspect of the accumulation of firm-level technological capability.

9 *Ibid.*, p.87

shift existing cost curves."[1] More specifically, innovation is understood as "*a change in some production function which is of the first and not of the second or a still higher order of magnitude.*"[2]

The disequilibrium caused by technical change necessitates difficult adaptations among firms to the changed environment. The situation starts to look ecological; the disruption of the ecosystem also opens up new opportunities for adaptation and flourishing of species; niches for this matter. Schumpeter aptly calls this economic space.

> "For some of the 'old' firms new opportunities for expansion open up: the new methods or commodities create New Economic Space. But for others the emergence of the new methods means economic death; for still others, contraction and drifting into the background. Finally there are firms and industries which are forced to undergo a difficult and painful process of modernization, rationalization and reconstruction." [3]

He adds:

> "It should be observed that these vital parts of the mechanism of economic evolution, which are readily seen to dominate many business situations and to produce results of fundamental importance, can never be revealed statistically by measuring variation in an index of production, or analyzed theoretically in terms of total output."[4]

The creation of economic space or market niche leads to a swarming towards new innovations by imitators as the copying or modification of newly introduced technologies become increasingly possible. In the Schumpeterian system such opportunities come in clusters and are unevenly distributed.

> "First , the innovations do not remain isolated events, and are not evenly distributed in time, but... they tend to cluster, to come about in bunches, simply because some, and then most, firms follow in the wake of successful innovation; second, then innovations are not at any time distributed over the whole economic system at random, but tend to concentrate in certain sectors and their surroundings,".[5]

The changes which result from these disequilibria are not smooth, as a Lotka-Volterra curve would tend to show, but proceed in jerks and rushes. But it is still possible to locate their epicenter. "In every span of historic time it is easy to locate the ignition of the process and to associate it with certain industries and, within these industries, with certain firms, from which the disturbances then spread over the system."[6] Schumpeter visualizes a situation where investment opportunities vanish and the entrepreneurial functions becomes obsolete, forcing the economy into near-equilibrium socialist practice.

> "A more or less stationary state would ensue. Capitalism, being essentially and evolutionary process, would become atrophic. There would be nothing for entrepreneurs to do. They would find themselves in much the same situation as generals would in a society perfectly sure of permanent peace. Profits and... the rate of interest would converge toward zero. The bourgeois strata that live on the profits and interest would tend to disappear. The management of industry and trade would become a matter of current administration, and the personnel would unavoidably acquire the characteristics of a bureaucracy."[7]

This was a glance into a future based on emerging realities. "Technological progress is increasingly becoming the business of teams of trained scientists who turn out what is required and make it work in a predictable way. The romance of earlier commercial adventure is rapidly wearing away, because so many more things can be strictly calculated

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1 *Ibid.*, p.91

2 *Ibid.*, p.94

3 *Ibid.*, p.134

4 *Ibid.*

5 *Ibid.*, pp.100-101.

6 *Ibid.*, p.102.

7 Schumpeter, Capitalism, p.131.

that had of old to be visualized in a flash of genius,".[1] Finally Schumpeter delivers his ultimate prognosis:

> "Since capitalists enterprise , but its very achievements, tends to automatize progress, we conclude that it tends to make itself superfluous — to break to pieces under the pressure of its own success."[2]

Schumpeter visualized an economic system that was flung far from equilibrium by innovation and one which returned to a stationary (near-equilibrium) state. The return of the economic system to a near-equilibrium state associated with socialist organization suggests that Schumpeter's break withe the neo-classical tradition was not as radical as it appears. The appeal to stable or near-stable systems that characterized the post 17th-century intellectual tradition influenced Schumpeter's thinking just as it did Marx's. Schumpeter's work, however, forms a significant starting point for the analysis of non-equilibrium economic systems.

3. Technology and Non-Equilibrium Economics

3.1 The Post-Schumpeter Period

Schumpeter has brought us to a crucial turning point: from this vantage position we shall examine the emerging non-equilibrium approaches in the analysis of technological change. One of the most significant contributions to the approaches has been the concept of learning. This concept has been extensively analyzed by David and has given rise to a series of studies in the developing countries, especially in relation to infant industries.

David treats "technological progress as fundamentally *an historical evolutionary process* ", in which "the future development of the system depends not only on its present state but also upon the way the present system was developed".[3] There is an element of historical indivisibility in this approach which enables one development to be linked to another. But the technical developments are local, neutral and stochastic: local because they are adaptive and incremental; neutral because they do not have any factor-saving bias; and stochastic because they do not manifest the Markovian processes which are drawn from classical mechanics. This process is not only endogenous but irreversible.

> "As a result... previous economic configurations become irrevocably lost, and in trying to work backwards by entertaining counterfactual variations on the present, one cannot hope to exhibit the working of historical processes."[4]

David combined the Darwinian concepts of survival of the fittest with what he calls "the Mendelian principle of *heredity*".[5] This established a link between factor prices, choice of technique and the rate and direction of global technological change in a "fundamentally evolutionary character".[6] Moreover, the "drift of technological developments generated over time within a fairly stable economic environment needs to be viewed... as a distinctively historical phenomenon, inasmuch as it may arise through the myopic selections past producers made from among the different species of techniques with which they originally had to work,".[7] This approach provides a useful starting point for examining firm-level technological change. However, it ignores the various extra-firm factors, such as institutional mechanisms, which influence selection. Furthermore, selection presupposes a search process that can only be understood by examining market

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1 *Ibid.*, p.132.

2 *Ibid.*, p.134.

3 David, *Technical Choice*, p.76.

4 *Ibid.*, p.15.

5 *Ibid.*, p.76.

6 *Ibid.*, p.61.

7 *Ibid.*

characteristics and firm behavior. For an evolutionary approach that includes both search and selection, we shall turn to Nelson and Winter.

Nelson and Winter reject the view that firms seek profit maximization and adopt the Alchian approach which stresses economic natural selection. Like Schumpeter, they discount the value of general equilibrium theory. But unlike Schumpeter, they discard the production function. Although the model is an attempt to break with neo-classical thinking, it still uses tools adopted from mechanical physics such as the Markov chain, a fact that has led David to argue that the model still "remains fundamentally neo-classical in spirit".[1]

This claim is based on the assertion that since the Markov chain is built on the present and not past situation, it is ahistorical.[2] However, the notion of search and selection, which is central to the model, assumes the pre-existence of technological possibilities; it must assume a historical retroaction. The process of innovation therefore involves both creating and discovering; both of which need a historical basis to take an evolutionary posture.

> "In many technological histories the new is not just better than the old; in some sense the new evolves out of the old. One explanation for this is that the output of today's searches is not merely a new technology, but also enhances knowledge and forms the basis of new building blocks to be used tomorrow,".[3]

The neo-Schumpeterian studies, so far as they emphasize evolutionary processes, assume technology as embodying known characteristics. They therefore do not engage with the process of innovation itself but emphasize its consequences. Moreover, the changing market environment requires that products adapt to the new conditions. The market therefore becomes a configuration of niches. Consequently, a product is designed to embody those characteristics that will enable it to adapt to a particular market niche. This is the message provided by Abernathy *et al.* in the model of technological de-maturity.

In this model, a product is a configuration of design concepts which are adapted to particular market conditions. But the introduction of another innovation may disrupt the market niche, making the existing capital equipment, labor skills, materials, components, management culture and organizations capabilities obsolete:

> The stabilisation of design concepts, in which industry maturity consists, makes productive units increasingly vulnerable to changes in technology, market preferences, and relative prices. As does a biological species that has become perfectly adapted to a particular environment niche, mature industries carry with them the implicit threat of extinction or, at least, catastrophe if environmental conditions should suddenly or radically shift.[4] As the product and process technologies evolve and develop, they become more robust in the way they accommodate the full range of variety in the existing environment. Like the tree that develops an extensive root system to weather the dry season it must occasionally face, management refines and perfects a product over time to better accommodate the range of variation in the market. Yet a product and process technology that becomes more highly organized and efficient... it also becomes more vulnerable to sudden and unanticipated variations in the environment. The highly productive, efficient and developed product unit is also more vulnerable to economic death.[5]

If the disruptions are trivial, then the firm can adapt by making incremental changes. But if they are substantial, then the firm is thrown back onto a new learning process. Such is the logic of de-maturity. From this vantage point, the market can be

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1 David, *op. cit.*, p.76

2 For a defence of the Nelson-Winter model, see Elster, *Explaining Change*, pp.156-157.

3 Nelson and Winter, *Evolutionary Theory*, pp.255-256

4 Abernathy *et al.*, *Industrial Renaissance*, pp. 28-29.

5 Abernathy *et al.*, Innovation, p.18.

conceived as an adaptive landscape where both products and the external environment (as well as the related institutions) constantly change.

Technology evolves over time. Its articulation trajectory is associated with complex institutional interrelationships. This evolutionary process makes it difficult to separate technical, economic and policy issues. Policy is generally conceived as intervention in the economic arena to achieve positive results. This already suggests purpose and change of trajectory. There would be no need to take policy issues seriously if the economic environment was settled in either a form of equilibrium or of 'self-organization'. In a constantly changing environment, policy must take on an evolutionary character. We therefore view policy as the purposive generation, selection, retention and evaluation of evolutionary options, under conditions of uncertainty.

Policy analyses therefore require the need to anticipate possible changes in the economic environment and introduce the required adaptation. This view differs significantly from the conventional approaches which emphasize 'adjustment' instead of 'adaptation'. This is partly because they assume equilibrium conditions and the required policy interventions constitute efforts to restore equilibrium conditions. This approach has very little learning effect on the macro-evolutionary process since it focuses on financial and monetary instruments. In addition, the approach may indeed erode the knowledge base because some of the neo-classical policies undermine the role of institutions.

It is important to recognize at this point that technological innovation is a social process and that the micro-evolutionary changes must be linked to macro-evolutionary dynamics. In other words, our macro-evolutionary analysis of social change must be done in such a way as to reflect micro-evolutionary reality. A departure from this view would lead us to the conventional situation where equilibrium analysis is superimposed on micro-evolutionary dynamics, a process which has resulted in limited recognition of the role of technological and institutional change in economic evolution. This makes the situation more difficult to deal with from a policy point of view. An evolutionary approach that emphasizes purposive action and stochastic reorganization provides a better handle for technology policy issues.

3.2 Micro-evolution and Technological Complexity

This section underscores the long-run evolutionary nature of technological change. The analysis is based on micro-evolutionary processes and illustrates the emergence of complexity and hierarchy in the process of technological change. It will be shown that the design of technological systems is purposive and guided by technical, economic, social and political interrelationships, which in turn influence its morphology. The emergence of technological systems is associated with the non-linear reorganization of the economic environment. The resulting changes are unpredictable and irreversible.

3.2.1 Analytical units and networks

One of the tactics used in conventional economics is to reduce complex processes to homogeneous units and then treat them as the central factors in the economics process. The 'firm' for example, is often treated as the fundamental productive unit, an irreducible 'whole' and what takes place within it is often treated as irrelevant. Likewise the household is regarded as the fundamental unit of consumption so that the notion of the household acting as a productive unit mobilizing and allocating its own resources so as to satisfy more fundamental consumption objectives cannot be encompassed easily in conventional theory.

In conventional theory, styled models have not been given a chance to 'evolve' towards a correspondence with reality. This is partly because by assuming equilibrium, the prerequisites for testability are eliminated and the model therefore cannot 'learn' or change in relation to real events. The common practice is to build assumption into a model and test it empirically. If the reality does not fit the model, then the situation is declared a paradox. Indeed, when the reality described by Schumpeter did not conform to the equilibrium ideas received from classical mechanics, Rosenberg declared it a paradox.[1] Or when households perceived as units of consumption deviate from the predicted behavior, they are termed irrational.[2]

We shall argue that the units of analysis are not isolated entities but nodes in a complex network of activity in a socio-economic system. Much of what goes on within the firm, both in structure and function, is integral to the process of economic change. What is significant therefore is the ensemble of institutional networks, involving firms as well as households. In this respect, technology takes on a new character; it becomes part of the process of social learning and cannot simply be viewed in terms of factor input ratios.

Although conventional economics treats the firms as the fundamental unit of production, the textbooks define the firm in financial and legal terms. We note, however, that the firm is not the most appropriate unit of analysis for the study of technological change, since the very act of production itself is unstable. Only in a world where technological change is exogenous to economic change, a neo-classical and static world, is the firm a homogeneous entity from a production standpoint. In all other circumstances the productive unit is a system with shifting boundaries — a world linked together by knowledge and learning networks. This view is consistent with modern research findings in which production is organized as both a network and a hierarchy.

For example, in industrial production, a supplier network might evolve with each of the secondary subcontractors acting as a repository of specific skills or competences with regard to a set of components or sub-assemblies which are then supplied to the primary subcontractor. The production system therefore forms a nested hierarchy with horizontal and vertical links which are defined by the flow of information, knowledge, skills and resources. The main company may be seen as a crucial node in a network which it co-ordinates to ensure the successful development of products. At the same time networks re-organize, dividing the labor process, exchanging information and developing tacit codes of conduct for their respective roles in the sub-system or system.[3]

But why should firms take this rather non-specific character instead of being irreducible entities that can be subjected to the vulgar selectionism of market forces? The answer lies in the fact that firms operate in a complex environment that is constantly changing. Their ability to continue operating lies in their capacity to adapt to changing internal and external conditions through learning. The organization of the network therefore reflects the need to maximize flexibility through learning. This is the same message provided by Toffler.[4] Apart from complexity, the economic environment is dominated by non-linear processes. This means that managers cannot continue using the same practices all the time. In such uncertain situations, linear and static concepts of the firm do not reflect reality. "Under such conditions, all organizations become extremely vulnerable to outside forces or pressures. All managers must learn to cope with non-linear forces — i.e. situations in which small inputs can trigger vast results and *vice versa*,".[5] Coping with non-linear situations requires effective information flow and systematic organization in which networking plays a significant role.

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1 Rosenberg, Schumpeter and Marx, p.208.

2 This was indeed the common view held by neo-classical thinkers about the adaptive and risk-averting behavior of peasant communities, especially in relation to new technologies. Like the firm, households are conceived as irreducible entities.

3 Clark and Juma, *Long Run Economics*.

4 Toffler, *Adaptive Corporation*.

5 *Ibid.*, p.ix.

Since the introduction of a new technological system in the economy represents a non-linear process, we argue that the most suitable way of analyzing the evolution of complex systems is to focus on the interrelationships and not on assumed irreducible entities. By emphasizing interrelationships, we may start to comprehend why economic factors tend to appear in hierarchical structures as the system moves through time.[1]

3.2.2 Technological systems and hierarchies

The evolution of technology is characterized by hierarchical organization. There is usually initial competition amongst functional units, sub-systems and systems which gradually leads to a small number of likely candidates. This process involves progressive market articulation as various market niches are experimented with. Indeed there is continuous feedback at all the stages of development as the technology gradually creates a niche in the market.

There are a number of examples in the recent innovation literature which illustrate the case of technological hierarchy. One of the most interesting is in Clark's proposed model of 'design hierarchy' which is evolutionary in character and emphasizes the interactions between customers and designers in industrial morphogenesis.[2] Clark portrays a model which emphasizes design logic and interactive feedback. Every design problem involves an effort to achieve a fit between 'form' and 'context' but since both are constantly changing they require guiding influences. This is provided by Rosenberg's natural trajectories which are driven by technological imbalances (or compulsive sequences), engineering vision, competitive and consumer feedback.

Thus technological trajectories, or paradigms, should really be seen as design trajectories which develop in a hierarchical sequence very similar to Waddington's "chreodes" along an epigenetic landscape.[3] For example, in the early stages of the automobile industry the embryonic 'form' of the automobile can be defined in terms of its functional parameters; motive power, steering, stopping, speed regulation, load capacity and so forth. "Each parameter pertains to a functional domain, but within any particular domain, there exists a set of alternative concepts among which the designer may choose."[4]

Thus early alternatives in car engine designs included electric, gasoline and steam while in semiconductor technology there were several rival methods for 'doping' base material to create a transistor. Today there are rival organisms (viruses, fungi and bacteria) for hosting recombinant DNA. Each functional domain acts as a core which sets the agenda for subsidiary choices in an expanding hierarchy for designing duct and valve arrangements in a nuclear reactor. Not only are design trajectories hierarchical but they are also reticular in the Koestler sense. They interact along functional domains in ways that allow for the emergence of a nested hierarchy, thereby creating technological systems of great complexity.

The evolution of designs does not stop with the producer but goes into the domain of household consumption, since consumers are faced with analogous problems. Using a similar approach Clark shows that we may view a new product as a form of consumption technology for the satisfaction of more basic needs. However, the consumer has to learn to do this, first by classifying the product in terms of already known products (concepts), and what they can do, secondly by combining the new product with other resources to sat-

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1 Moreover, this view provides a more realistic picture of the role and behavior of institutions at the various stages of technological change.

2 Clark, The Interaction of Design Hierarchies, pp.235-251.

3 Waddington, *The Strategy of the Genes*, Chapter 2.

4 Clark, *op.cit.*, p.237.

isfy needs, and thirdly by feeding information back to producers regarding how product design might be improved.

Another example of technological hierarchy is Sahal's portrayal of evolution through *scaling*, the analogue of morphology in biological evolution.[1] For Sahal, all coherent technological systems may be defined in terms of ratios of physical dimension among components; and the development of any given system occurs through a process of physical scaling (increasing in the case of aircraft technology, for example; decreasing in the case of modern computers).

Systematic changes occur either where scale shifts run into bottlenecks <u>or</u> where new technological possibilities radically alter system configurations (for example, due to the advent of new materials) <u>or</u> (the 'revolutionary case') where two or more systems converge (as in the jet engine from propulsion technology and turbine technology). Such changes then create new 'dominant designs' which provide the trajectory for further technological advance. The act of technological entrepreneurship becomes one of identifying where the important bottlenecks and potential breakthroughs are and thence mobilizing the necessary resources to ensure commercial success.

Sahal likens the process to that of an 'anti-gravity' ball rolling along a low basin in an unknown topographical landscape, somewhat akin to Waddington's embryonic phenotypes transversing their "chreodes". Technological success is to be seen in terms of the ball reaching the top of the highest hill in the locality but of course while the ball is in the valley it does not know which pathways to choose out of those that it encounters at various points of intersection.

The situation is rather like that of a traveller without a map in an unknown country — the lower the valley, the greater the difficulty in choosing the right track, but in this case the topography itself is slowly changing as a result of socio-economic and political factors (analogous say, with a series of very gentle earthquakes). Choice of pathway is never completely uncertain, however, since the traveller has knowledge of landmarks ('technological guideposts') which give clues provided they are correctly interpreted.[2]

3.2.3 Purpose and morphogenesis

A technological system is a combination of several technical units which evolve differentially and are brought together to perform a certain function. This makes technological evolution a purposive and not a random process. The importance of the evolution of individual units is explained by the structure and function of the whole system. A technological system is therefore viewed as a convergence of co-existing functional units. The patterns of change among the units, both functional and allometric, is governed by the purposive imperative of the whole system, and not vice versa. This is mainly because the technological system is designed to fulfil certain pre-conceived goals which could be achieved by various technical configurations. The range of such technological systems is narrowed down through a selection process that attempts to match the adaptive parameters of the systems to the key features of the external techno-economic environment. The increased matching of these parametric sets may be viewed as an increase in techno-economic performance.

There is no technological system that is perfectly adapted to the environment or has the ultimate techno-economic performance. This is partly because of limitations in the internal structure of the systems themselves and the constant changes that occur in the external environment. What technological innovation does is to constantly improve the

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[1] Sahal, <u>Technological Guideposts</u>, pp.61-82.

[2] If they are, the traveller is successful, and indeed becomes more certain the nearer he gets to his goal. If they are not, he may have to retrace his steps and try another track.

adaptive parameters of the system either by matching previously unmatched environmental features, or by adapting to new changes.[1] This is the logic of increased techno-economic performance, which does not necessarily mean a perfect adaptive fit. This process of raising the techno-economic performance enters into a new phase if the environmental changes are radical and disruptive enough to threaten the survival of hitherto existing systems with new adaptive features.

Alternatively, the discovery of either a technical unit or a system that has a higher techno-economic performance may threaten the existing system. The displacement of technological systems is often accompanied by periods of co-evolution in which an existing system may be modified so as to enhance its adaptive parameters. The modifications are likely to be made in those parameters where the competing technological systems have an 'advantage'.[2]

If the design of a technological system is taken as the unit of selection, the conjectural technological variants are not generated through blind or random variation. However, the variants still have to be further tested in the operating environment through the process of niche realization. This suggests that the process of error-elimination continues from the point of conception of a particular technological possibility to the stage of niche realization and beyond. Moreover, shifts in the environment may require changes which can be achieved through incremental improvement and not necessarily by the scrapping of the technological system. Exogenous pressures as well as internal technical imperatives induce incremental innovations.

The initial entry of a technological system into the market is therefore just the beginning; the system is constantly subjected to both internal and external pressures requiring constant innovation. This means that the system remains in a state of partial success until competing systems dislodge it. [3] The rate at which systems are dislodged is complicated and depends on factors such as the size and characteristics of the market, the economics of scrapping, costs of research and market entry, perceived profits and production scale. What is important here is the process of the generation of conjectural technological variants, which is usually through research, development and demonstration. Changes in the environment may also lead to the movement of technological systems from one niche to another without any form of distinctive divergence. Such divergence is a common aspect of technological evolution. For example, the Caterpillar farm tractor developed in Stockton, California in 1904 was later turned into the military tank and used in World War I. The two technological systems occupy different niches and continue to change in functional and systematic complexity by taking on new functional units. What is interesting is not the phylogeny of technological systems and the associated dendrograms, but the process of technological variation, their selection and retention.[4]

Apart from distinctive divergence, systems may also be moved from one niche to another without undergoing major internal changes. This may happen at times of major environmental changes which open up new opportunities for systems which could not otherwise have survived. The example of the fuel ethanol is illustrative of this. The technologi-

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1 In other cases, firms may pre-empt the imperative to innovate by altering the external environment to suit their techno-economic performance and reduce competitive pressures. This can be done through a large number of protectionist measures. This view suggests that the environment is also subject to pressures from firms, which constantly endeavor to create suitable environmental conditions for their survival, akin to the Gaia hypothesis.

2 For example, the introduction of continuous ethanol plants forced manufacturers and users of batch systems to introduce innovations which save energy, reduce inputs and improve the overall performance of the plants. For details, see Juma, *Evolutionary Technological Change*, Chapter 4.

3 For the philosophical basis of this view, see Popper, *Objective Knowledge*.

4 See Wik, The American Farm Tractor, p.126.

cal system evolved in the beverage environment and although its energy potential was known, the dominance of petroleum made it uncompetitive in the energy environment. It was not until the oil crisis that the potential for realizing the ethanol niche was enhanced. This made it possible to use on a large scale the technological systems from the beverage environment in the energy environment. [1]

3.2.4 Non-linear and irreversible changes

We have so far shown that technological change tends to evolve towards higher forms of complexity and nested hierarchies. These changes are irreversible since they are associated with time flow. This development is closely linked to internal systemic requirements to achieve the required function of the need to process larger pieces of information to adapt to a particular market niche. For complexity and hierarchy to emerge, the technological system undergoes non-linear changes associated with the introduction of new technical information. Some of the recent studies in incremental technical change at plant level have tended to show a linear picture of technical change.

According to these studies, technical change at firm level is viewed as following a particular path associated with the accumulation of indigenous technology capacity at firm level. The fact that indigenous technological change is cumulative gives a false picture of linearity. This is partly because the studies are usually retrospective and do not capture the non-linear, stochastic processes that underlie the process of incremental innovation.[2]

The generation of technical information is a constant process. This may be in the form of problem-solving at plant level or new inventions contained in patents. This continuous technical drift is both a result of varying degrees of uncertainty and a source of unexpected changes in the techno-economic terrain. The effect of any new information is difficult to predict. What is certain, however, is that the information, especially when embodied in technologies, re-organizes the system in non-linear ways. The re-organization may occur at plant level with minimal systemic effects. However, the convergence of large quantities of technical information may lead to major economic transformations. This is the case with technological systems associated with micro-electronics.

These changes are non-linear so far as small incremental changes may trigger major transformations in the technological regime. Equally significant is the fact that the changes entail a qualitative shift in the knowledge and competence base. In addition, the market environment in which the innovations compete changes unevenly and therefore the prospects of entry are unevenly distributed over time and economic space. Moreover, the changing market environment requires products to adapt to the new conditions. The market therefore becomes a configuration of niches. Consequently, a product is designed to embody those characteristics that will enable it to adapt to a particular market niche.

A product is a configuration of design concepts which are adapted to particular market conditions. But the introductions of new innovations (technological and organizational) may disrupt the market niche, making the existing capital equipment, labor skills, materials, components, management culture and organizations' capabilities obsolete. This is a source of major discontinuities in the technological terrain. These discontinuities may lead to new product and process lines as new niches are created, or the the substitution of

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[1] For a detailed exposition of the taxonomy, evolution and classification of organizational systems, see MacKelvey, *Organizational Systematics*.

[2] This misconception is compounded by the fact that the methods employed to quantify the impact of indigenous technological change are based on aggregations and therefore reduce the complex learning process to a few numerical values such as output, downtime, productivity efficiency, and input reduction.

existing products and processes.[1] it is because of the non-linear processes associated with technical drift and niche creation that new technologies emerge.[2]

It should be noted here that the emergence of new technological lines will not always displace existing ones even if the former have superior functional characteristics. Once technologies are settled into the market environment, they become so intricately linked into the social system as to resist displacement. This is exemplified by the case of the current typewriter keyboard.[3] The typewriter keys were arranged specifically to reduce the speed of typing due to technical difficulties associated with high typing speeds in the early stages of its development. Despite the existence of numerous superior alternatives, the QWERTY arrangement has persisted. Alternative keyboards such as the Dvorak Simplified Keyboard (DSK) would increase the speed of typing by up to 40%. "Moreover, during the 19th century, U.S. Navy experiments have shown that the increase efficiency obtained with the DSK would amortize the cost of retraining a group of typists within the first ten days of their subsequent full-time employment".[4]

3.3 Macro-evolution and Technology Policy

In order to understand the links between the technological change and policy issues, it is important to examine political processes in an evolutionary light. Party politics or variations in political ideals are largely a reflection of differences in the way groups of peoples perceive the future course of their social evolution. It is at the political level that major efforts are made to change the future. This gives politics its evolutionary character. Long-run technological development is an *in situ* process; it relates to the endogenous development of local capability to undertake specific economic activities. This, however, does not mean that localized learning does not have system-wide effects. This, indeed, is the non-linear nature of new knowledge introduced into the economic environment. There are variations on the ability of countries or economic units to learn from localized knowledge generation.[5]

In most developing countries policy learning is hampered by the limited flow of newly-generated information. This is exemplified by the limited learning that has occurred as a result of the failure of industrial projects initiated in the 1960s and 1970s. Policy leaning tends to be effective in areas where the political agenda is directly influenced by long-run economic imperatives or where long-term economic policies are not directly affected by changes in the political arena. These two situations illustrate the need for continuity in policy learning. In Japan, for example, long-term economic policies are not affected by party politics in any major way.[6]

It is interesting to note that in most African countries, technological change has not become a major political issue. Instead, the political agenda is defined largely along macro-

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[1] See Tushman and Anderson, Technological Discontinuities, for an analysis of the role of technological discontinuities in competence and destruction.

[2] A phyletic reconstruction would however reveal a complex flow of technical, social, political and ecological information which impinges on the emergence of new technological lines or bifurcations. Such a flow cannot occur under equilibrium conditions; the very nature of technological innovations suggests that the economic environment is in a constant state of disequilibrium.

[3] David has attributed this to technical interrelatedness, economics of scale and quasi-irreversibility. See David, Clio and the Economics of QWERTY, p.332-337.

[4] *Ibid.*, p.332.

[5] The capacity to do so depends largely on the ability of the existing institutions to retain and reproduce the acquired experiences. This is what constitutes policy learning.

[6] In countries where party politics has major influences on prevailing technological policies the accumulation of particular stocks of policy knowledge may be stalled.

political questions such as monetary and fiscal policies as well as administrative issues. Technological change, which is the main source of economic change, is still a relatively minor item on the political agenda. This is true even of those countries that have previously been major technological powers.[1] This suggests that conventional views are still the main sources of policy guidance even on issues where they are clearly losing ground. The existence of such conditions makes it even more difficult to argue the case for the institutional requirements of technological innovation.

There are other ways in which political factors influence technological development. Often short-term political goals are used to justify long-run technological development. Since short-term objectives do not often incorporate learning requirements, projects designed under such conditions are likely to fail or can only be sustained over the long-run through increased government support. Such cases are prevalent in both the industrialized and developing countries. [2] Technological failure is largely a result of bureaucratic organization and practice.

Under conventional practice, the regular activities required to fulfil the requirements of the bureaucratic machinery are distributed in a fixed manner as official duties or functions. Those tasks which fall outside each jurisdictional domain are often ignored, explained away or passed on to other officials. As described already, evolving situations tend to increase in complexity. But since the functions are distributed in a fixed way, new requirements for technological development cannot be met without destabilizing the bureaucratic system. The bureaucratic machinery, on the other hand, is meant to remain in a stable state and government officials are empowered to maintain it thus.[3]

Furthermore, the bureaucratic rationality that is accorded government departments is based on the view that all the knowledge that is required to implement investment projects is available and all the necessary resources can be mobilized through government fiat. But the problems that the projects encounter are largely related to the fact that every step in the implementation process is non-linear and requires new pieces of knowledge.[4]

The manner in which government officials tend to handle information limits the capacity to learn from emerging situations and contribute to adaptive change. The manage-

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[1] This statement does not hold for military technology.

[2] See Borins and Brown, *Investments in Failure*, for a study of technology failure in Canada. This case raises questions of the capacity of governments in general to invest in technological projects. In addition to the political pressure to invest in particular regions, the structure of most governmental institutions is inimical to technological learning. As pointed out elsewhere, the institutional organization required for technological change is different from that already retained by most governments. The excessive hierarchy and jurisdictional borders limit the information flows required to facilitate the project implementation process. The findings of the study are consistent with the reasons for the failure of a fuel ethanol plant in Kenya. See Juma, *Evolutionary Technological Change*, Chapter 6.

[3] This mechanistic view of institutional organization was perfected by Max Weber in his description of the ideal bureaucracy; an analogue of an efficient machine which fulfils social objectives in a rational, scientific and efficient way.

[4] Evidence from recent efforts to open up niches for appropriate or intermediate technologies shows clearly that technological development requires flexible, adaptive and semi-autonomous institutions which assume uncertainty and therefore emphasize learning and the flow of information (through dynamic networks). It is therefore not surprising that non-governmental or volunteer organizations have been in many cases more effective than state institutions in facilitating the introduction of new technologies, especially for energy production and utilization. See Juma, *Evolution of Improved Cookstoves in Kenya*, for an evolutionary interpretation of the development of cookstoves in Kenya, with emphasis on the role of non-governmental organizations' networks.

ment of a government office is based on written documents in files, which are preserved in draft or original form. This information is hardly synthesized or analyzed to extract useful lessons. In addition, such files are kept secret and the information is therefore not freely subjected to recombination or selection for purposes of institutional or technological innovation.

The organizational skills required in project implementation are different from the bureaucratic capabilities of most civil servants. One basic difference is that government officials are trained to handle linear situations; there is a chain of command or a bureaucratic hierarchy that has to be followed. Project implementation, however, has non-linear imperatives and management must be prepared to deal with a network of inter-relationships which do not respect rigid hierarchical structures.

4. The Way Ahead.

This study has shown that the 300 year grip that Newtonian concepts have had on economic thought is starting to loosen. New ways of looking at reality are becoming increasingly consolidated. The realities of technological change are starting to show the dynamic nature of economic processes and therefore make the static reductionist metaphors of classical physics less relevant. Mainstream economic thought has yet to come to terms with the philosophical and practical implementations of non-equilibrium ideas. However, numerous attempts are being made to create new intellectual niches in which non-equilibrium ideas can take root. This is not a simple task; it will take global co-ordination, serious research and long-term commitment. So far, economics is one of the most Newtonian of the social sciences. As in the Prigoginian world, the process will involve a long-term process of moving from being to becoming.

Art and Science

by

Hans Nordenström

The question of the relationship between art and science, and between artists and scientists, leads me to ponder the creative processes involved in scientific research or in creating a work of art. I feel this to be more in line with the newly emerging complex, dynamic paradigms of our time.

Art has many faces and forms, just as science does with its many branches ranging from physics to philosophy. But while there are even such obvious similarities, there remain sufficient divisive factors to make attempts at staging encounters between artists and scientists often rather frustrating. It seems that they 'speak different languages', making the risk of misunderstandings in co-operative efforts quite obvious. Even the generally accepted observation that artists and scientists have quite separate lifestyles is apparently an obstacle to mutual understanding.

But the core reason behind what divides artists and scientists is hardly the rapidly advancing avant-garde of modern research and its sophisticated technology. The explanation lies rather in the strongly polarized view we have of both, which includes stereotypes of both artists and scientists. This view is so deeply rooted in the common consciousness that it usually forms the starting point for discussions on this question. C.P. Snow's short paper on the "two cultures"[1] is still frequently referred to.

Our black-and-white thinking comes historically from "modern thinking", the modernist movement, founded in the Age of Enlightenment with its worship of Reason, which resulted in a positivistic scientific ideology, and an unholy mixture of romantic and modernist ideals in art.

Today, in the '80s, debate seems to culminate in calling into question this long tradition. There are, of course, among the debators, many groups of irrational mysticists, but I choose to leave them out of this discussion. But fortunately, things are happening in analytical philosophy, which sees both art and science as instances of the same general endeavor to understand and shape reality. The concepts of truth and knowledge are common to both.

Thus arises the provocative statement: that science could be seen as a form of art. Scientific research appears also to exhibit certain styles, and the transitions from one scientific style to another could be said to be analogous to the development of styles in art, such as the Gothic and Renaissance styles, Mannerism etc.

Theories, Facts and Concepts

The background to these statements is the modern view on theories, facts and systems of symbols (among these, language). The traditional view regarding theories has been, as we well know, that they are verified or refuted by being confronted with reality. Reality has been looked upon as something independent, for both the theory and the observing subject. Facts are discovered, not created. Facts constitute the only real world and knowledge consists of belief in these facts. The main task of language in science is to reproduce the ready-made world.

This previously well-established view on theories, facts and languages has now, I believe, been rejected on all points. Einstein, like Feuerabend more recently, realized that theories are fictions; that they are free inventions of the human spirit. Theories are built up from the verbal constructions we call concepts. Concepts are conventional categories of

[1] C.P. Snow, The Two Cultures, 1963.

thought - human artifacts - which are not identical with sensory impressions, but go far beyond them.

Furthermore, theories are not wholly formulated from data obtained from observation. Two quite incompatible theories can be consistent with the same set of data. History shows also that a theory may be accepted even in spite of its inconsistency with what is accepted as fact at the time of its gaining ground. Political and/or financial interests, prestige, lust for power or even purely aesthetic factors may in some cases weigh more heavily than facts.

Facts in their turn are dependent on theories. The shift from one theory to another can bring about profound changes in all the facts within the domain of that theory. The "new" facts dependent on a "new" theory cannot, on the whole, be meaningfully compared with the facts derived from an earlier theory.

Facts, therefore, are also created. Just like concepts, they are artifacts. There is not just *one* factual world, but a multitude of factual worlds, or "versions" as Nelson Goodman[1] describes them.

If theories are fictions and facts are dependent on theories, then it must be concluded that there is no unshakeable order, no ultimate foundation of knowledge, no absolute truth.

Symbolic Systems

Language does not map the world, it creates worlds. Words can exist without a world, but not a world without words. And the world with which we are most concerned consists of thoughts rather than matter. The basis of activity in art, as well as in science, is some kind of perception. But without concepts we have no structures on which to hang our perceptions. We would be perceptually blind. To see is an active, creative process. When a sensory input has been transformed into a perception, it has already become conceptual and linguistic. A world without language is a world without characteristics.

Neither art nor scientific theories provide a direct representation of reality. They provide only indirect representations via a symbolic system of some kind. Realism in art depicts what we are used to. The realities of our world are as much a legacy from novelists, dramatists and painters as they are from scientists. The truth of metaphors in art is not less true than scientific truths. Art, as well as science, discovers, creates and extends our knowledge.

And now from modernism to post-modernism. Post-modernism is an ambiguous concept; seen on the one hand as opposing modernism, and on the other as the latest manifestation of modernism. But I believe the basic thesis of post-modernism to be the critique of what has been called "the totalizing reason". I see it as a fruitful attempt to balance a former one-sidedness. Many post-modernists seem to share the view that there is no outlook which is free from language, from which the relationship between language and the world could be observed. According to Derrida "there is nothing outside the text".

A central aspect of the post-modernist movement is its attempt at developing what Castoriades has called a "reason exceeding itself", which in accordance with the new paradigm, has the potentiality of becoming historically a project of man in our time, which will avoid the traps of both messianism, and cultural and political regression.

The post-modern artist, the artist of today, is not in the same situation as the philosopher: his work is not guided by any given rules. The artist works without rules: his work is to establish rules for what is to come. He proceeds by negating those rules laid down by previous art. (This idea emanates from Kant.)

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[1] Nelson Goodman, Ways of Worldmaking, 1978.

Jean-François Lyotard[1] argues that a work of art today can only be modern, if it is first post-modern. Post-modernism in this sense is not the end of modernism, but its birth, in the iterative wheel of shifting paradigms. Lyotard therefore accepts nothing as genuinely artistic except initiatives or events, wherever they occur.

Ethics in Art and Science

And now to the more crucial question of responsibility, morality and ethics in both art and science.

Works of art are not complete in our heads beforehand, and the creative process also implies some sort of craft. The process is an internal affair, personal, even private. It is an aesthetic discourse, not a simple message. When I am writing or painting, I am both producer and audience, and the work develops within the limits I have chosen – limits that are necessary when anything is permissible.

What interests me now, is the process of creation of works of art, rather than how they are used. Art requires our complete capabilities, emotional and intellectual: our experience, knowledge skills, and courage, faith, doubt and intuition. Art is a challenge. And it simply won't do to be theoretically naïve.

I believe in art that is conscious of itself, a meta-art. Making life itself an art has been hailed by many as worth striving for, but seem unfortunately to be an unattainable ideal. An aesthetic, critical attitude is, however, a necessity. It fulfills our basic need for order and articulation, for giving some structure to the almost infinite multiplicity and conflicting values in our world.

Art is also a matter of wonder and wondering. It is the signs and symbols of our existence. And it is what might be called the existential – that which is represented in works of art with rich potential for international interpretation and universal applicability.

Existence and Appearance - Two Aspects of the World

The use of signs, the interpretation of symbols, production of signification is what most human activity is about. Semiotics[2] is a tool for understanding objects as vehicles for symbols, as traces of something that has occurred, an absent structure. We direct our attention to the signification of phenomena – what is signified by works of art, their creation and their symbols – which means that we "de-realize" the objects. We apply this "de-realization" to every phenomenon: every object, event or action. The expression of it replaces the object itself. The starting point is always two aspects, such as being and appearance, substance and form, the imaginary and the real. Things both "are" and "appear to be". Semiotics is a part of our reflection on the world and reality. We are confronted with the appearance of the world, and we postulate its existence.

Art and science are different choices of approach in our quest to alleviate our intellectual and emotional angst. Science seeks the specific in the general, while art seeks to bring out the universal or common from the particular. A theory makes something visible. 'Theater' and 'theory' have the same root in the Greek language. The roots of science

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[1] J-F. Lyotard, La condition postmodern, 1979.

[2] Semiotics: The theory of signs and symbols, has developed during this century in three different fields of science: in logical empiricism (the Unified Science movement, aspiring to a formalized, unambiguous basic language of science; Cassirer, Langer); in linguistics (F. de Saussure and others); and in philosophy, the French structuralism (Barthes, Bandrillard, Darmisch, Derrida, Greimas, Kristeva, Lacan), in Italy (Eco, Ginsburg), in the United States (the prominent Russian-American Roman Jakobson and Paul de Man). In this paper I refer mainly to the French tradition. The basis of semiotics is the notion that man produces extremely complex symbolic systems. Semiotic research focusses on just this one question: what is the meaning or signification of any phenomenon, object, artifact, event or activity?

are magical, from the number mysticism of the Pythagoreans to the imaginative hypotheses of modern physics and astronomy. To inscribe a phenomenon under a common law is what natural scientists call explaining the phenomenon. Conformity to the law is the explanation. New findings transformed into technological applications provide greater control over the forces of nature. And control is power. But most findings will be refuted. Our knowledge does not grow, but only shifts. We may become cleverer, but not wiser. Wisdom does not seem to be in demand in our part of the world. The insoluble riddles, those which are 'just' simple paradoxes, we remit to the philosophers, who are thereby guaranteed full occupation. But we do not become good human beings by reading ethics, nor artists by studying aesthetics.

There are, however, alternatives. We can turn outwards, or we can turn inwards. We can choose measurement or meditation, which seem to be ultimately branches of the same tree in seeking for what *is* in what *appears to be*, i.e. the imaginary. But art is different. Art does not seek, art creates realities; symbols for the imaginary. Art thereby lacks qualitative development or progress.

Different ways of observing the world result in the discovery of different aspects of it. A way of looking at the world is a form of insight. Different perspectives are not different approaches to knowledge. They don't provide us with information about what the world "is". Rather, they are simply different outlooks.

To understand is to change systems. Investigating must not imply directing the force, for that is to correct and crush it. Analyses should be adornment – as in art. Analyses should aim at a new and unprecedented form of consciousness.

Poetry is a clear example of the way in which art forms deliberately manipulate symbols; in direct contrast and even violation of the discursive syntax of science which aims at the unambiguous and freedom from contradictions.

The Cognitive Content in Art

Julia Kristevea[1] shows in her studies of the history of Western culture that poetry, ballads, poems and odes are the key to a deeper understanding of societal development. Thus, reading Dostoyevsky will probably give us a greater insight into the human mind than reading a psychology textbook.

Works of art can reflect and defuse the absurdities and passions of existence, while scientific research hardly touches the enormous diversity of human existence; the incidental and divergent, the world in which people sin, love, fear, exercise power and practise violence; from Caliban to Prospero, from tyrranical ruthlessness to venerable wisdom. The task of art is to keep the myths alive, to force us to remember them and develop them further.

There is a remarkable degree of similarity among the mythologies of the great world cultures with regard to their conceptions of origins, the human condition, procreation and virtues. Western civilization is comparatively young. The myths resurrected in Western art are inherited from earlier highly developed cultures. Gilgamesh saved his ship and all his animals on the seventh day on the mountain of Nisir, long before Noah's Ark was stranded on Mount Ararat. The doctrine of finality is omnipresent, and this theme is rich in variations. Whether the final catastrophe starts with a flood, storm, a severe frost or earthquakes is a question of geography and climate – or in out time, perhaps technology, nuclear power.

Art as an Agent of Social Change

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[1] Julia Kristevea, Polylogue, 1977.

How then do we cope with our own future and the threat of total destruction? The younger generation is greatly concerned. If the domain of art is the human condition, in what manner can it contribute to and stimulate greater efforts in living? It cannot be through discursive participation. Symbols in art are non-discursive by nature, but nevertheless created with a deeply critical attitude, inevitably expressing the conflicts of our time. In this sense, art must make decisions regarding ideological and social issues.

The dominant concentration on natural sciences and technology in our time also in itself contains powerful symbolic dimensions. The question which remains is if art can develop visions and modes of expression capable of mediating and critically illuminating this radical process and its social and moral implications. This might be the artistic challenge for our time. It could include two fields of activities: an art of science and a science as art, both aimed at making visible the gap between technical and aesthetic scales of values.

There is freedom because freedom is the basis of practice. History shows that even conversion is possible, the ability to gain control over oneself. Humanism is the idea that there is in each one of us a human nature which we only need to bring to light, in order to liberate. But basic freedom also implies the possibility of creating oneself – even though this is done within the limits of the prevailing dominant structures that have been shaped by hundreds of years of culture.

The existential "duality" is a perpetual movement between freedom and captivity, and the task of art is to reveal this reality.

Artistic endeavor is a means of producing oneself. It is revolutionary and like other revolutions implies a responsibility towards societal development in the wider sense, something which is not often the case with scientific research or the tactical maneuvers of politicians. The enormous potential for revolutionary changes in the conditions of life represented in works such as those of the poet Mayakovsky are not tolerated by despots such as Stalin. Language creates man. Art is a critical discourse which expresses inner demands, and consequently it must be quashed by dictatorships. Its ideologem, that which places the work into the present, must be destroyed. But I want to believe that true art suffers only setbacks.

The Concept of Time in Artistic Work

Artistic creativity is released in moments of inspired improvisation, in oppostion to consolidation of given structures, the status quo. The critical questioning that this entails, with its fluctuations between intensive periods of concentration and idleness, resembles the rhythm of activity of agrarian societies. It is the pattern of what we today call "free creative work", and is a direct threat to the predominant idea of a disciplined work process. To 'kill time' is a sin. Time in the industrialized capitalist world should be used, consumed, invested. In contrast, the time scale of artistic work is similar to that found in developing countries. Effective maximizing of resources stands in contrast to quality of life – labor instead of work.

Industrial society has an insatiable appetite for inventions and planning. Planning begins with the premise that our present living conditions do not satisfy our pretentions, and the hope that things will be better in the future. But the belief that technological advances and inventions can solve social problems has become a widespread neurosis, with the consequence that life itself is becoming a series of provisional arrangements.

An Aesthetic of Existence

A society dominated by eagerness to invent delimits art to a specialization, a field for experts. Aesthetic values are given to artefacts, objects and buildings. But true art, what is called avant-garde, questions at a basic level human patterns of action. Such profound reconsideration is apprehended as disturbing the order, because the dynamic power of art cannot be relegated to articulated expression in structured objects. Artistic performance or exercise is a process, a manner of conduct, aimed at creating an altruistic ethic which could constitute an aesthetics of existence. The focus of aesthetics is the sensuality of the present. The ethics of art is to *be* good rather than to *do* good. Desire, longing, is more important than enjoyment, even if the object of desire is absent, something lost or unattainable.

However, I do not mean to oversimplify the place of art in the society. Arnold Hauser[1] has shown how the role of the artist in the society has changed throughout art history. Art as a mirror of life or as a critical voice in the society is a highly charged polarity, and a dilemma for the irresolute. And unfortunately, art can indeed be exploited inappropriately, as the Nazi ideals and practice in art and architecture bear horrifying witness to.

What art must do is go to the depths of the human soul, expose and affirm the irrational within us, including the destructive, and thereby enable us to disarm it.

In contrast to the self-righteousness of Fascism, art stands for the courage to make mistakes. This is an essential element. The artist experiences the pain of starting over and over again; trying, failing, yet having the courage and strength to try again. In truth, it is art which is really uncompromising.

To write poetry is to exorcise one's sorrow and, to quote the American poet Robert Bly, "to preserve the moisture in one's frog's skin". We have a rationalist within us that urges us to burn it, but if we get rid of the frog, we lose access to certain ancient instinctual resources within ourselves.

The Schizophrenia of Basic Values in Life

Man's basic values are absolute qualities. Nevertheless, we have to learn to live with discrepancies, incongruities and antagonisms, because the basic values of life constantly prove to be at odds with one another. We try then to categorize them and rank them in hierarchies. Isaiah Berlin[2] shows that when we believe we have succeeded in doing this, we are led into an unshakeable faith, a certainty, that leads to fanaticism and war. In principle, we cannot judge and condemn, but in practice, we are forced to do so all the time. Our souls have to live a schizophrenic life regarding our deepest questions.

The task of art should be to develop a sound scepticism in confronting this tragic dilemma. It requires self-criticism and humor to face this schizophrenia of values in society and in life. The truth of life is the highest standard of art – that is how Bertolt Brecht saw it.

Works of art are complex products, fantasms shaped by both visions and considerations, expressions of experiences of the rhythms of life, its softness and its ruggedness. The activity itself, like an ideology or philosophy of life, has a tendency to totally absorb its believers. Conviction can turn to blind faith. But he who can laugh at his own convictions will never be engulfed by them. Laughter preserves one's intellectual and spiritual freedom. The Taoist master Lao Tzu said that if you cannot laugh at it, it is not Tao. And Zoroaster, the Persian magician laughed on his first day of life. (Jesus, however, is not recorded as ever laughing. Christianity is a grim religion.)

When sorrow and pain are awakened, what the Swedish novelist Lars Ahlin calls "the private traffic" is threatened. It is a threat against our ability to create on our own initiative. The value of each man is unique, and if we are seduced into adjusting ourselves to the "world of comparisons", and climbing the hierarchies of values, then we are guided by

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[1] Arnold Hauser, The Social History of Art, 1982.

[2] Isaiah Berlin, Against the Current, 1979.

"helical" desires. The "private traffic" is a sign of health, and it is inescapable. We can overcome paradoxical realities with humor by accepting the dualistic, contrasting nature of life. Humor is the art of dialectics. The humorist stands up to the variety and multiplicity of the world.

The Productive Eros

I suppose that the points I have tried to make regarding the conditions of art, and especially the moral issue, are equally valid for science as well, despite the deep-running differences between the two with regard to both means and ends, which I have also touched upon. But it is still my firm conviction that art and science can and must come closer together in understanding, and develop a closer co-operation. This would re-establish the synthesis between longing and production, between the beautiful and the useful, the key to the productive Eros.

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Science and Art: Newton's Influence upon the Arts

by

Florence Hetzler

Sir Isaac Newton, though by his own admission not particularly interested in art, has had an immense influence on all of the arts. The impact of Newton's literary work upon the world can be felt by those working in mathematics, by anyone who throws an apple from a window, in fact by all who walk this earth and expect to continue to do so from the beginning of that walk until its completion. The science and methodology of Newton have resounded from their source in Cambridge right around the world. What is not so well known, however, is the impact upon the arts that this man, despite the fact that he himself (though he did write a few verses when young) was interested neither in creating works of art nor in the appreciation of them. The few drawings found under the wallpaper in a bedroom he once occupied stand in strong contrast to the influence he has exercised upon the world of art.

Marjorie Hope Nicolson had indicated the influence of Newton's *Opticks* upon 18th and 19th century poets in her book *Newton Demands the Muse* [1]. For her contribution in this area we are very grateful, and it is my intention here to complement her work. There is much more that can be said about Newton's influence upon all the arts. In this paper Newton's *Principia* and especially his *Opticks* will be considered not only as scientific treatises but also as works of literature.

Newton is proof positive that creativity cannot be decreed either in science or in art. The new direction in science that was taken by Newton had more impact upon the art world than he would have liked, and certainly more than is generally known. It is this influence to which this paper is addressed. The co-creativity of art and science goes on.

In the year 1987, the 300th anniversary of the publication of Newton's *Principia* [2], one may see this very work exhibited as a work of art in a prestigious art gallery: the J.Pierpont Morgan Library in New York. This work, titled in full *Philosphiae naturalis principia mathematica* and published in London by Joseph Streater for the Royal Society, is open at pages 50 and 51, where we find Newton's drawings of his ellipsis and of his parabola. These too might be considered works of art. In his introduction to a modern edition of the *Opticks* [3], Einstein wrote:

> "Fortunate Newton! Happy childhood of science! To him, Nature was an open book whose letters he could read without effort. His conceptions seemed to flow spontaneously from Nature itself, from the beautiful experiments which he ranged in order like playthings, and described with an affectionate wealth of detail."

We see here the importance of play and imagination in the creativity of genius. We believe firmly that Newton's *Principia* and his *Opticks*, in addition to being works of science, were also works of great literature. Metaphors of light, movement, gravity, color are found throughout, and tend far beyond the printed page. There is not just fact; there is universal resonance and relevance in these works of Newton.

The relationship between art and science, and for our purposes between the science of Newton and art, has taken a long time to reach the public. The art and science of both Leonardo da Vinci and Galileo have been researched (for example, see Reference 4) but there is more to be done concerning Newton and the arts.

It was not only poets who were influenced by the new approach to light and color; by alchemy; by the law of gravity; by the interest in the earth as a planet in a great solar system; and by a new vision of space made available by Newton. Newton himself appears in a painting that reveals the response of the painter as well as that of the other figures who appear in the painting. I refer to "Christ's Entry into Jerusalem", a work by Benjamin

Haydon (1786-1846) which, during its lifetime, has travelled a great distance from the studio in London where it was created, first to Edinburgh and Glasgow and then to Philadelphia's Academy of Fine Arts, where it remained until the disastrous fire of 1840 when it was cut from its frame by firemen and dragged out. It was then taken to Cincinnati's Cathedral and later to the Art Museum of that city, and finally to Mt. St. Mary's Seminary there. Nicolson refers to that painting on the very first page of her *Newton Demands the Muse* [1] which she begins by writing:

> "The immortal dinner came off in my painting room," Benjamin Haydon wrote in his diary for December 28, 1817. "Wordsworth was in fine cue, and we had a glorious set-to on Homer, Shakespeare, Milton, and Virgil. Lamb got exceedingly merry and exquisitely witty, and his fun in the midst of Wordsworth's solemn intonations of oratory was like the sarcasm and wit of the fool in the intervals of Lear's passion...... He then in a strain of humour beyond description, abused me for putting Newton's head into my picture; 'a fellow' said he, 'who believed nothing unless it was as clear as the three sides of a triangle.' And then he and Keats agreed that he had destroyed all the poetry of the rainbow by reducing it to its prismatic colours. It was impossible to resist him and we all drank 'Newton's health, and confusion to mathematics.'"

In this painting are Wordsworth (1770-1850), his head bowed in reverence; Newton (1642-1727) who is looking on calmly and serenely; Voltaire (1694-1778) who seem to be sneering; and John Keats (1795-1821). Keats made his position clear in his "Lamia" where he wrote:

> Philosophy will clip an Angel's wings,
> Conquer all mysteries by rule and line,
> Empty the haunted air, and gnome mine —
> Unweave a rainbow.

William Hazlitt (1778-1830) is also in the picture, a literary critic and essayist among the great writers and scientists. It is also said that Landseer painted the animals in the painting, and that this is the best part of the work. The portraits of Voltaire and Newton are, of course, purely imaginary, since they were long dead when the work was created. That Newton should appear in such a painting is not at all unexpected, since he was very interested in theology. He wrote books on the reasonableness of Christianity and made studies of the epistles of the New Testament. Some say that he regarded his theological studies as the important business of his life, and that all about physicality was extraneous and merely explained how God had constructed His physical creation.

The Haydon painting therefore, is not true to reality. It may be an influence of Newton on art *per contra*, as were most of his earlier influences on art. In the Haydon painting, Newton is presented as someone who did not like theology because he was an alchemist. This is wrong: we know that the last part of his life was devoted to theology[5]. In the 19th century there may have been a romantic aura surrounding alchemy, as in the case of Shelley and of some painters who painted scientists doing experiments, but we must not forget that in Newton's day, alchemy was the equivalent of the chemistry of today. It was not astrology, nor was it mysticism[6]. In the painting Wordsworth appears to be more open. In his "Prelude" he wrote of Cambridge:

> where the statue stood
> Of Newton with his prism and silent face,
> The marble index of a mind for ever,
> Voyaging through strange seas of thought alone.

We are familiar with Shelley's "Adonais" where he speaks of the "many-colored glass" that "stains the white radiance of Eternity" and of Shelley's response to science, made clear by Carl Grabo in his book *A Newton Among Poets* [7]. Pages could be written on the influence of Newton upon people like Blake, who through negative criticism brought more attention to Newton. A visit to the Fitzwilliam Museum in Cambridge and to its collection of works by Blake makes it clear that Blake did much to call attention to Newton. Alexander Pope did also in his "Essay on Man", though this was on the positive side.

We also believe that the atmosphere at Cambridge's Trinity College when Charles Darwin (1809-1882) was there, was prepared by the ideas of Kepler and Newton. We believe that Darwin's *Origin of Species, Descent of Man* [8] and *Voyage of the Beagle* [9] are works of both science and literature, and that they were influenced by the science of Newton. Gillian Beer of Girton College, Cambridge, has done more than anyone else to establish Darwin as a writer of literature[10]. John Gage of the Department of History of Art, Cambridge, agrees that there "is poetry in Darwin's writing and indeed in all pre-modern and especially descriptive writing, where the distinction between science and imagination is blurred"[11]. Darwin had the metaphor of organicism while Newton had that of mechanicism[12]. The atmosphere of Cambridge must have had a great influence upon Darwin.

Newton had brought to law many of the raw facts of science and had given great credibility to observation and conclusions in science. Newtonian matter meant in part force that attracts: it meant gravity power. Darwin's matter was that of co-evolving, fulfilling, selecting, changing and transforming. His power was of the co-evolution of species. He transformed unchangeable species into changeable species. This is analogous with Newton's gravity. Gillian Beer[10] writes of Darwin's view of relatedness, which is not unlike that of Newton: "What Darwin emphasizes is relationship... the sense of progeny and diversification, of a world in which profusely various forms co-exist, unseen and yet dependent... "(p.45) The meaning of force and matter in Newton is explained in Ernan McMullin's *Newton on Matter and Activity* [13], while that of Darwin is made clear in the *Origin*. Darwin's selection theory might be compared to Newton's gravitation theory, and as I have indicated, there is a connection between the natural selection and species differentiation of Darwin and the gravity theory of Newton.

McMullin writes that Newton, in the final version of Rule III of the Principia, "hesitantly adds attraction" to what we know to be the "primary qualities of earlier seventeenth century thought". McMullin adds that for Newton:

> Attraction is one of the universal qualities: indeed, it is attraction that he is probably most anxious to qualify as universal. Yet it is clearly not given us in experience, as, for instance, the mobility of a body is. It "appears by experiments and astronomical observations", he says, "that all bodies gravitate towards the earth", and that "our sea gravitates towards the moon". (p.24)

L. Robert Stevens, in his book *Charles Darwin* [14], states not only that the works of Darwin are literature but that those of Newton are also. I believe that Darwin's works were literature possible largely because of Newton's scope and because of the atmosphere at Cambridge, so favorable to science. Stevens says that both Darwin and Newton had an English education that had, as its strength, "a protestant impatience with arguments from authority, an incredible tenacity in observation, and an *a priori* belief that orderliness is not only a personal convenience, but also the definitive mode of knowledge"(p.18). Darwin, who entered Christ's Church, Cambridge, exactly 100 years after the death of Newton, had a great sense of wonder about the universe, just as did Newton. Their scope was global. In Darwin's last book one can see the vision in which the contemplation of the specific becomes infinite. An old man looks at earthworms and acknowledges "that there is mystery enough in a square foot of soil to occupy the curious mind for a lifetime". Stevens says:

> Charles Darwin's work does indeed constitute a body of literature. It accords the most profound definition of literature to say that the liveliest revelations of the scientific mind have always expressed themselves in great literature. Galileo's *System of the World* is literature; Newton's *Principia Mathematica* is literature; .....that is they all communicate ideas of universal consequence for mankind with clarity and force. (p.58)

Stevens says that Darwin's "revelation is both art and science: it is also history and philosophy, and the ability to unify these studies into a harmonious whole is a characteristic which Darwin shares with Newton, Goethe and Einstein." He also says that Darwin and Newton, along with Einstein, made us see more than we had ever seen before, and this he says is the common denominator with art. He states: "As Newton brought both celestial and terrestrial physics under the same scheme, so Darwin opened the possibility that man might be included in the same physics." (p.130). Both Newton and Darwin had multi-faceted approaches to the multi-faceted real. Each was a genius in his own field. The potentiality of their intellects coupled with the potentiality that matter *is*, as well as with the potentiality that they saw as matter, made not only for good science but also for good literature. It seems to me, however, that without the daring vision of Newton and his literature Darwin would not have dared and probed the world of biology and geology as he did.

It is small wonder that the prose writer Thomas de Quincey (1785-1859), who believed that literature of power gave vital being and meaning to things and this forever; after saying that the "very highest work that has ever existed in the literature of knowledge is but a provisional work, a book on trial and sufferance and *quamdiu se bene gesserit*"; adds in his *Literature of Knowledge and Literature of Power:*

> the *Principia* of Sir Isaac Newton was a book militant on earth from the first. In all stages of its progress it would have to fight for its existence: first, as regards absolute truth; secondly, when that combat was over, as regards its form, or mode of presenting the truth. And as soon as a La Place, or anybody else, builds higher upon the foundations laid by this book, effectually he throws it out of the sunshine into decay and darkness, by weapons won from this book, so that soon the name of Newton remains as a mere *nominis umbra*, but his book as a living power, has transmigrated into other forms.

Nicolson[15] reinforces this theory of de Qunicey when she writes that "Newton used as one proof of his theories the color and sound correspondences between the prismatic colors and the musical scale. Mystic numbers were not only the stuff of poetry for metaphysical wits..." (p.36). She quotes Pope's "perfect epitaph for the Newton who was the father of modern science, the Newton who in his *Principia* formulated the fundamental law of the universe and described that universe as it continued to be described until yesterday". After writing of the "Newton who gave the final death-blow to the old theory of an animate earth, who proved that both the world and the earth are mechanism", she adds that "there was another Newton, more concerned with his interpretations of Daniel than with the mechanical laws of the universe, a Newton who was the son of Kepler, the mystic." (pp.155-56).

Newton had yet another global vision that could have influenced Darwin. The daring of this as well as of his scientific approach and his fresh start at Cambridge was part of his legacy to Darwin. What Newton was to the heavens, to light and to space, Darwin was to the skin of the planet, to biology, to the morphic and evolutionary[16]. The theory of gravity founded by Newton was applied differently by Darwin. Pope's epitaph for Newton indicated that Newton did, indeed, have the power to influence Darwin and his literary works.

> Nature and Nature's laws lay hid in night.
> God said, "Let Newton be!" and all was Light.

It is true, or course, that Newton used high mathematics in his formulations of the law of gravity, but it is also true that vision and light were involved in his conclusions from observation. The *Opticks* seems not sufficiently studied, either for its importance for Newton or for his influence upon artists and the arts. Certainly Nicolson believes this to be so. I. Bernard Cohen, in his preface to the *Opticks*, says that the *Principia* has "its mathematical demonstrations and general avoidance of speculation" while the *Opticks* has "large speculative content." (p.XXV) Cohen says that the mathematics of the Principia and its celestial mechanics can have influenced Voltaire, but that in the *Opticks* there was:

> a rich intellectual feast for philosophers as well as scientists, for poets as well as experimenters, for theologians as well as painters, and for all amateurs of the products of human imagination at its highest degree of refinement. (p.XXXVI)

Newton disavowed the use of hypotheses in the *Opticks* [3]. Certainly Darwin did the same in his approach to the people of Tierra del Fuego or the finches and tortoises of the Galapagos Islands. We might also compare with Darwin's approach, Newton's statement that "it seems probable to me, that God in the beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles, of such Sizes and Figures, and with such other

Properties, and in such Proportions to Space, as most conduced to the End for which he form'd them... "(p.XIV). Was it not shape, color and function that largely influenced Darwin to establish his theory of co-evolution in the cases of the iguanas and marine turtles on the various islands off Ecuador? Can the theory of gravity be a source of the theory or evolution and species differentiation?

Part of Einstein's preface to the *Opticks* [3] has already been quoted. He also says:

> In one person he combined the experimenter, the theorist, the mechanic and, not least, the artist in exposition. He stands before us strong, certain, and alone: his joy in creation and minute precision are evident in every word and in every figure. (p.LIX)

Einstein here makes Newton not only one who influences artists by his speculative and non-mathematical approach in the *Opticks*, but also a literary figure and a writer of literature. Indeed he was a man of great imagination and creativity. These concepts are not different in science from what they are in art.

Genius in arenas of creativity often causes fear in others. Darwin's conclusions about evolution in a world of creationists did, indeed, cause fear just as did the mechanistic theory of Newton upon the stage of an animate universe and also his theory of light and color upon a stage where light was akin to the divine. In the time of Darwin there were those who believed that each insect had to be created directly by God. Even Fitzroy, captain of the "Beagle" was a creationist, and it took vision as well as nerve to use observation alone and no pre-conceived hypotheses to come to the conclusions that Darwin did. He did not have the mathematical equations that Newton had had to give him credibility, but he had the ship's artist to make drawings for him. His books, indeed, were works of both science and art.

Darwin was involved in the biological microcosmic and macrocosmic. In Newton's thought the concepts of microcosmic and macrocosmic gave rise to thought about the planets as we see in Voltaire's *Micromegas* ; Jonathan Swift's *Gulliver's Travels* ; Jules Verne's *Around the World in Eighty Days* and *Voyage to the Bottom of the Sea* ; Cyrano de Bergerac's *Voyage to the Moon* ; and St Exupéry's *The Little Prince* of our own day. The *Principia* gave impetus to the literary cosmic voyage. The moon's importance and that of the plurality of worlds was seen anew in drawings as well as in literature. In Fontenelle's *Conversations upon a Plurality of Worlds* , St John the Evangelist suggests to Astolfo:

> a flight more daring take
> To yonder Moon, that in its orbit rolls,
> The nearest planet to our earthly poles.

In *Voyages to the Moon* [17] Nicolson says that although writers of space voyages, (and here she cites Kepler, Godwin and Cyrano de Bergerac) realized their debts to older writers such as Plato, Lucian, Cicero, Plutarch and even the sayings of Pantagruel and Don Quixote, the new philosophy and the new science of Newton provided a source of "materials to inflame the imagination even more than had literary traditions... "(p.22). She also notes that Swift, in 'Voyage to Laputa", endows the tiny world of Laputa, which was only 'four and one half miles in diameter and the terrella was only four and one half inches in diameter', with measurements not accidentally in direct proportion to the measurements of the earth given by Newton. The diameter of Swift's Laputa reckoned in yards is 7837, while Newton's figure for the earth's diameter is 7837 miles. Nicolson writes: "Swift's figures here are so close to those given in his time for our terrestrial globe by both Newton and Cassini that this cannot be mere coincidence." (p.193) Numerous examples of a similar nature might be cited. We might also cite *Le Philosophe sans Pretention ou l'Homme Rare* of 1775, a tale in which a visitor from the planet Mercury appears to Nadir while he is reading a book about mystical philosophy. This might be a satire on Newton's "scientific alchemism" which was taken to be mysticism. However, it must be borne in mind that comparably, in Newton's day, alchemy was not mysticism but chemistry[18,19].

Newton's interest in the movement of the planets, in gravity and in the theory of the air inspired much literature and even drawings of space voyages. When great men died, poets spoke of their cosmic voyages, as Christopher Pitt did when the Earl of Stanhope died, or as Ralph Cudworth did when Newton himself died. For him Newton's:

spirit flew, with sails unfurl'd
Through each vast empire of th' ideal world,
Pierc'd through the mystic shades, o'er Nature thrown,
And made the world's immensity his own.....

The god-like man now mounts the sky,
Exploring all yon radiant spheres;
And in one view can more descry
Than here below in eighty years.

Though Voltaire may have wanted in his *Micromegas* to put an end to this "nonsense" of Newton-Influenced cosmic voyages in literature, this genre persisted. We have again an influence *per contra* , a reaction to Newton's so-called alchemy. The color theory given in the *Opticks* also challenged Goethe to write *per contra* . In so doing he made Newton better known, just as Blake did with his anti-Newton statements and art works.

The power of art cannot be overestimated. A great example of the power of a work of art for making Newton known in Russia is Fontenelle's *Entretiens sur la pluralite des Mondes* , which was translated into Russian. The translation of *Micromegas* into Russian also helped in making Newton well-known. In the book *Newton and Russia: The Early Influence, 1689-1796* [20], Valentin Boss writes:

> However, it was probably not a work in prose that most vividly brought Newton's name before Russian readers but a poem, whose author (wrote the translator) has "penetrated into the greatest subtleties of Metaphysics".
> He was referring to Pope's *Essay on Man* , which if Warburton's words are to be believed, was "not a system of *Naturalism* , on the philosophy of Bolingbroke, but a system of Natural Religion, on the philosophy of Newton."(p.224).

Although the translators of the poem into Russian made changes to avoid naturalism, "Russian readers would have recognized the vivid portrayal in the poem of the workings of Newtonian gravitation"(p.225).

Pope's poem not only espoused the theory of gravity but also the theory of light. In fact Nicolson[1] wrote that "Pope said the last word on 'Physic' and 'Metaphysic'". She quotes from *The Dunciad* where Pope expressed "in truly 'sublime' style both the majesty and terror of universal darkness." Since Pope seems to combine the 'Physic' and the 'Metaphysic' I would like to repeat part of Nicolson's quote from *The Dunciad* to indicate some of Newton's influence on the arts that in turn made him well-known.

In vain, in vain — the all-composing Hour
Resistless falls: the Muse obeys the Pow'r...
Before her, Fancy's gilded clouds decay,
And all its varying Rain-bows die away...
Thus at her felt approach and secret might,
Art after Art goes out, and all is Night...
Philosophy, that lean'd on Heav'n before,
Shrinks to her second cause, and is no more.
Physic of Metaphysic begs defence,
And Metaphysic calls for aid on Sense!
See Mystery to Mathematics fly!
In vain! they gaze, turn giddy, rave, and die...(pp.130-31)

Astronomy is everywhere throughout Pope's thought. He had read the *Opticks* and had a great deal of respect for Newton. In the following passage from his *Essay on Man* it was not Newton but the Newtonians that Pope was chastising. We should not misunderstand this passage.

Go, wond'rous creature! mount where Science guides,
Go, measure earth, weigh air, and state the tides:
Instruct the planets in what orbs to run,
Correct old Time, and regulate the Sun...
Go, teach Eternal Wisdom how to rule —
Then drop into thyself, and be a fool!

Superior beings, where of late they saw
A mortal Man unfold all Nature's law,
Admired such Wisdom in an earthly shape,
And shew'd a NEWTON as we shew an Ape.

Pope's imagination was, indeed, inspired if not by Newton, at least by Newton's pupil Whinston. Pope pursued in poetry Newton's great wonderment about color, air, planets and infinite space. Nicolson, in her book on Alexander Pope[21] had made this clear.

A direct reference to Newton's prism was made by Pope in his color study in *An Essay on Criticism* which, though written earlier, was published in 1711. Pope wrote:

False Eloquence , like the *Prismatic Glass,*
Its gawdy Colours spread on *ev'ry place:*
The face of Nature we no more Survey,
All glares *alike* , without *Distinction* gay:
But true *Expression* , like th' unchanging *Sun,*
Clears, and *improves* whate'er its shines upon,
It *gilds* all Objects, but it *alters* none.

In this same work Pope, "describing the process of artistic composition... contrasts with a later period the moment of creation, when a new world leaps out at the poet's command." (p.269). This is the moment when the universality of creation takes over, when there is the unifying of experience, experiment, science etc. in a global view, in art. This is the creative moment that Newton, Darwin and Pope found, the moment when symbol meets symbol. Only one symbolic order can challenge another symbolic order. There is Newton's gravitation challenging Darwin's co-evolution: his rationalism challenging Darwin's observation: Newton's alchemy challenging Darwin's species blur and also challenging the poetry about nature brought about by both Newton's and Darwin's theories: and yes, there is the symbolic order of Fitzroy's creationism that challenges Darwin's evolution theory as well as the mechanistic theory of Newton.

The Newtonian work on color that raised the consciousness of Pope was challenged by Goethe, who was not a writer only. For a long time Goethe thought that his most important work was his theory of colors. For him there was a difference between thinking in and constructing. Reason is the difference between constructing and thinking, according to him, and science is constructing and not thinking. He was against the white-light theory of Newton and wrote his reaction in the two volumes of his *Farbenlehre* (Theory of Colors). This sensitivity to color that was his challenge to Newton indicates that his works of art were influenced by Newton's theory of color and light, even if *per contra* .

In the introduction to his annotated translation of *Goethe's Theory of Colors* [22] Charles Eastlake says:

> English writers who have spoken of Goethe's "Doctrine of Colours", have generally confined their remarks to those parts of the work in which he has undertaken to account for the colours of the prismatic spectrum, and of refraction altogether, on principles different from the received theory of Newton. The less questionable merits of the treatise consisting of a well-arranged mass of observations and experiments, many of which are important and interesting, have thus been in a great measure overlooked.(p.VII).

Eastlake makes a relevant observation here, namely that Newton's theory of color as given in the *Opticks* "seldom appears in a form calculated for direct application to the arts". The reason for this is Newton's admitted disinterest in art and aesthetics. Goethe, on the other hand, was an artist, a writer of great literature. In his own preface to the first edition of his *Fabenlehre* Goethe says that in the second part, the polemical part where he examines Newton's theory of colors, he calls it that theory "which by its ascendancy and consideration has hitherto impeded a free inquiry into the phenomena of colours."(p.XXI). Since he admits that this second part is rather dry, he introduces a comparison between Newton's theory and his, an analogy which might be considered an artistic metaphor. He compares it to an old castle that was built initially "with youthful precipitation" but which gradually received additions according "to exigencies of time and circumstances." These circumstances were sometimes the means of holding off enemies.

> But the old castle was chiefly held in honour because it had never been taken, because it had repulsed so many assaults, had baffled so many hostile operations, and had always preserved its virgin renown. This renown, this influence lasts even now: it occurs to no one that the old castle is become uninhabitable.

Newton's theory challenged Goethe's ideas and sensitivities, and these in turn affected Goethe's writings. As a kind of finale or dismissal of Newton, Goethe, just before he begins his work, says that people who are interested in nature and gradations will be more interested in his own theory. Newton's theory seems to give nought to aesthetics, according to Goethe: speaking of his own theory he says that "... in entering this theory from the side of painting, from the side of aesthetic colouring generally, we shall be found to have accomplished a most thankworthy office for the artist." In the "Notes" Eastlake speaks of the dealing with light and color on the part of such artists as Leonardo da Vinci, Titian, Giorgione, Rubens, some of the Flemish and Dutch masters, Reynolds, Correggio, and even of Goethe himself.

Eric Forbes[23] writes:

> Goethe, in his *Fabenlehre*, made an uncompromising attack upon Newton's experiments which was seen by David Brewster as an attempt to supplant the inductive stream of newtonian natural philosophy with the *Naturphilosophie* of the German Romantic school of thought. Goethe criticised the mathematical physicists for their preoccupation with quantifiable phenomena and consequent neglect of qualitative attributes. The advantage of his colour subjectivity as well as objectivity and in a wider physiological and psychological context: its prime disadvantage was that while accounting qualitatively for many observable phenomena, it failed to yield accurate quantitative predictions. (p.9).

Newton and Goethe were not alive at the same time and they could not debate their respective color theories, but it seems that the works of Sonia and Robert Delaunay, their rainbow-like "Rhythms", use both quantitative color from Newton's *Opticks* and the subjective color of Goethe's *Fabenlehre* [24].

In the catalogue for a 1987 exhibit of Sonia Delaunay in Bremen[25], we read that for both Robert and Sonia Delaunay

> it was their shared interest in color that led them to collaborate on a new theory of painting between 1910 and 1912. Labeling their concept "simultaneity", they proposed that pure color, independent of the external world and yet handled so as to suggest the faceted and overlapping quality of visual perception, could be the primary subject of a work of art.

It does not seem that the Delaunays could have worked on their color without acknowledging both the light cause of Newton and the subjective element of Goethe. What is important for our purpose is that Newton was the point of departure, even if *per contra*, for Goethe. He did not like Newton's statement that "all the Colours of the Universe are made by Light, and depend not on the Power of the Imagination." It is not without reason, therefore, that Forbes[23] adds in his summary:

> This historical example raises the question of the adequacy of current scientific enquiry as *the* means by which we seek to attain Truth, and exemplifies the need for a study of the history of science that will reveal both the limitations of its hypothetico-deductive methodology and the role of imagination in scientific creativity.

This is an interesting spin-off from the Newton/Goethe color problem that has been discussed by artists and has influenced many of them, including the Delaunays, Josef Albers and others[26].

Carl Grabo explores the effect upon Shelley of Newton's color theory as well as Shelley's metaphysical conception of matter that is taken from a kind of Newtonian mysticism. Grabo says that the influence of Newton's work in optics is evident in certain passages on light and color in Shelley's poetry. In *A Newton Among Poets* [7], Grabo writes:

> Shelley's interest in light and color is everywhere manifest in his verse. Vision was to him the master sense. He is essentially an eye-minded poet... In Newton's *Opticks*, or in the scientific writing subsequent which is based on Newton, lie explanations which serve to elucidate some of Shelley's lines. That Shelley read the *Opticks* is not certain, though two allusions to Newton may be noted in his letters. But the copious work upon the phenomena of light to be found in Shelley's day suffices to explain this knowledge.(p.90).

For Shelley, as for Wordsworth and Blake, there is no clear line of distinction in color. All is blended. There is no line of distinction between Man and God either. Even Blake says "Thou art a man and God is no more/ Thy own humanity lent to us all."

Prof. A. Rabin of the University of Jerusalem has told me that Wordsworth's 60-word poem "My heart leaps up when I behold a rainbow in the sky" gave the author great trouble. Why? In the *Prelude* Wordsworth speaks of Newton and of his prism at Cambridge. Wordsworth was interested in painting, his painter friends and colors. But why the rainbow? Because he had a kind of holistic philosophy, a kind of neo-Platonism, according to many, in which everything is included in the I and the not I, and what the not I is we do not know. We create our not I and so we are doing the work of God in our own small way. This holistic philosophy does not leave boundaries between things. In a rainbow there are no lines of clear distinction, and so the rainbow serves him as a model, paradigm or symbol of his entire view of the world. There, in the blending of the colors of the spectrum and in the impossibility of determining where one color ends and another begins, we go back to Newton. Grabo makes this clearer perhaps:

> Colors, then, reside not in objects themselves but in the power of these objects to absorb and reflect the various constituent colored rays which compose the white light of the sun... Harmony and discord in color, may, Newton thinks, arise from the proportions of the vibrations propagated through the fibres of the optic nerves into the brain. He draws an analogy from the harmony and disharmony of sounds. Strictly, then, color is a sensation in the brain dependent upon the length of the light waves which beat upon the optic nerve.

Vibrations do not, indeed, make for clear lines of color but for blendings, as we see in Wordsworth, Shelley and Blake[27]. In this article Newton and Painting[11], John Gage

> attempts to outline the ways in which painters tried to reconcile the newtonian doctrines with their own experience, and (the article) takes as its foci theories of colour-mixing and of colour-harmony. It also traces the growing preoccupation with colour-perception during the century.(p.16)

Newton's *Opticks*, he says, had even before the Romantic period been required reading for landscape artists. In his article Gage proposes

> to deal not with the general background to the acceptance of Newton's work among painters, but to look briefly at two more precisely documented instances of its effect. One is rather practical, and concerns methods of colour-mixture: the other is almost purely theoretical, and deals with a newtonian phase in the search for principles of colour-harmony. Both involve the concept of primary colours.

After saying that Newton's color theory first came out in the *Philosophical Transaction of the Royal Society* in the 1670s, Gage speaks of Newton's circular diagram of color mixtures that was in 1704 *Opticks* :

> This circular diagram became the model for many color systems in the eighteenth and nineteenth centuries, from the supplement to the *Traité de la Peinture en Mignature* attributed to Claude Boutet, in the Hague edition of 1708, where the seven-colour division (with two reds) seems clearly to reflect the newtonian arrangement of four years earlier, to the first completely symmetrical and complementary colour system of Moses Harris, *The Natural System of Colours*, published about 1776.

Because Newton quantified the components of white light and explained the proportions of colors in the spectrum of this white light, there was a "new impetus to assimilate the aesthetics of sight to those of hearing, and to give the new science of color the benefit of many centuries of investigation into the principles of musical harmony." Although this analogy appears in Query 14 of the *Opticks*, Gage quotes from a fuller explanation that was not published until the middle of the 18th century but which was written in 1675, in a letter to the Royal Society: Newton wrote that "as the harmony and discord of sounds proceeds from the proportions of the areal vibrations, so may the harmony of some colours, as of golden and blue and the discord of others, as of red and blue, proceed from the proportions of the aethereal". A French Jesuit, Louis Bertrand Castel, who invented the ocular harpsichord, was initially influenced by Newton's verification of the link between sound and light but, Gage tells us, Frank Kupka's "Discs of Newton" was "perhaps the only series of paintings to be based directly on newtonian ideas about color".

Newton, when he was young, made toys and objects that moved. He would be at home with contemporary kinetic sculpture. Nicolas Schöffer's "Lux,1959"; brass with luminodynamic projections; Jean Tingueley's "Prayer Wheel" of 1954, a work in steel that is motorized; Picabia's "Amorous Procession" of 1917; Gabo's "Vibrating Spring"; Laszlo Moholy-Nagy's "Light Machine" of 1930; Schöffer's "Cybernetic Tower" and Tingueley's "Metamechanic No. 9" bear witness to the theories of Newton. So does the entire 'Chronos' series of Schöffer. There is also a musiscope: the percipient may play what looks like a piano and in so doing cause colors to be placed upon a screen. Jean Cassou[28], formerly Chief Curator of Le Musée d'Art Moderne in Paris, has written of Schöffer what seem to be a synthesis, ultimate at least for our day, of Newton's color and light theory and also of his analogy with sound:

> Ingenious modifications in the adjustment of his machines would permit him to make light and color give off a dazzling variety of effects. And a new birth, that of Chronos I in 1969, heralded a new art, yielder of new delights, "chronodynamism". For now it is to be time which patterns and modulates itself in these new works. This art is identified essentially with music in it keys like those of the most glorious instruments are played upon to produce a flow of chromatic movements of chromatic tempos, like that of a musical score, with a diversity and power of the same order, the diversity and power of a symphony — not to mention the fact that to these effects of color are added the most sumptuous effects of shadow, of light and of color intensity.(pp.18-19).

Newton made drawings for his mechanical machines much as kinetic artists do today. There does not seem to be a great difference between Newton's approach to perpetual motion machines and those of Duchamp, Robert Morris, or even Brancusi, who put a work of sculpture on a phonograph turntable. An artist in spite of himself, yes, we can call Newton "L'Artiste malgre'lui". He was avidly involved in drawing these mechanical works, which can be looked at as works of art even though they were not so intended. Although his motion-works, much like the mobiles of Calder, were not commonplace things, they may be looked at aesthetically, as Danto says, do "what works of art have always done - externalizing a way of viewing the world, expressing the interior of a cultural period, offering itself as a mirror to catch the conscience of our kings."(p.208). The drawings of Newton have, in addition to the significant form, the sensuousness of which Suzanne Langer speaks. They are a great legacy to the world of art.

Richard Westfall[19] tells a story which he admits may have a "touch of whimsy" but it must also have some truth. He says that despite the gentle remonstrations of Stokes, Newton persisted in drawing and in making his "mechanical contrivances." Westfall writes:

> He could not leave them alone even on the Sabbath, although it filled him with remorse. We know that Newton found many of these contrivances in a book called The Mysteries of Nature And Art by John Bate... Newton took extensive notes from Bate, on drawing, catching birds, making various-colored inks, and the like.(p.61)

Later Newton lived in an apothecary shop and "became proficient in drawing."

> ... A later occupant of the garret room testified that the walls were covered with charcoal drawings of birds, beasts, men, ships and plants. He also drew portraits of Charles I, John Donne, and the schoolmaster Stokes. A few circles and triangles also appeared on the walls — more of a forecast of the Newton we know than all of the portraits and birds and ships together. And on nearly every board, testifying to his identity like the desks in the school, stood the name "Isaac Newton", carved and therefore indelible.(p.67).

An artist in his literary/scientific writings as well as in his drawings, Newton would not admit to being a lover of the arts, even later when he was living in metropolitan London. Westfall adds:

> According to Conduitt, he never diverted himself with music or art. "Never" was too strong, for Newton did tell Stukeley that he went to the opera once. He found it too much a good thing, like a surfeit at dinner: "The first act," he said, "I heard with pleasure, the 2d stretched my patience, at the 3d I ran away." As for art, all he could think to say about the Earl of Pembroke's famous collection of statues was that Pembroke "was a lover of stone Dolls."(p.581).

Westfall says too that:

> "Villamil remarked the absence from his library of any of the English classics — Chaucer, Spencer, Shakespeare, and Milton — and of poetry in general. Years later, on doubtful authority, he was reported to have described poetry as "a kind of ingenious nonsense."

What would have been the reaction of Newton to an array of his painted portraits, for example the miniature of Newton at 71 by Christian Richer in 1714; John Vanderbank's portraits of him in 1725 and 1726; or Thomas Murray's portrait of Newton at 75 and Thornbill's of 1710? There is also the ivory bust sculpted by David Le Marchand in 1714. It seems that it would be worthwhile for a museum such as the Fitzwilliam in Cambridge to present an exhibition not only of the poems that include allusion to Newton but also the portraits made of him. Indeed, an exhibit of his drawings, such as his drawing of a plan of the Jewish temple, could be the main feature. Someone might also give a lecture on a comparison of Newton and Darwin as scientists/artists, indicating influences of Newton upon Darwin. There is a real sense in which Newton was not only a sketch-artist, and architect-artist, but also a literary-artist. The exhibit might also include the Blake works that make fun of Newton, as well as Newton's designs for medals drawn when he was at the Mint; for example, the design for the coronation of Anne, where Newton made annotations to explain why he put certain images in the design.

It is not with levity that I mention a TV program called "Newton's Apple". On August 9, 1986, there was a program on moving in space at zero gravity. It featured Dr Jeffrey Hoffman, an astrophysicist at MIT and a former astronaut who has been in space. Appropriately for the name of the program, Jeff explained what zero gravity meant. He explained that one day people would be living in space colonies in a different gravity. The story of Newton's apple has occasioned a television presentation in which his theories are presented in 20th century language. His theory of gravity has unseen applications in our world. Living in zero gravity is an option and will give rise to a new aesthetics of transportation, architecture, etc.

Newton's notion of gravity is supposed to have come to him in a garden under the shade of some apple trees at his home in Woolsthorpe. Christianson[30] tells us that this fall of the apple occurred when Newton was sitting in a contemplative mood. He adds:

> Newton evidently told much the same story to his niece, who, in turn, passed it on to an admiring Voltaire, through whom Newtonian thought was popularized in eighteenth-century France. In the English translation of his *Elements de la Philosophie de Newton*, *le philosophe* wrote: "One day in the year of 1666, Newton, having returned to the country and seeing the fruits of a tree fall, fell, according to what his niece Mrs Conduitt has told me, into a deep meditation about the cause that thus attracts all the bodies in a line which, if produced, would pass nearly through the center of the earth."(p.78).

And so, Newton had occasioned television people to televise just as he motivated William Blake to paint, even though the latter painted Newton *per contra*. David Bindman[31] has given some of the Blake background:

> Blake's first Illuminated Books, dating from towards the end of the 1780s, *There is no Natural Religion* (no.38) and *All Religions are One*, are direct philosophical assaults on Deism or Natural Religion, insofar as it sought to incorporate the discoveries of empirical thought into the doctrine of the Church of England. To Blake Deism was the religion of the rulers of England, nothing less than 'the Religion of the Pharisees who

murder'd Jesus': he was tireless in his condemnation of philosophical empiricism in all its forms, naming Bacon, Locke and Newton as preachers of doubt and despair.(pp.16-17).

Blake has executed in color print with pen and watercolors a painting of Newton, done from 1795-1805. It shows a man who for Blake was cut off from his own spirit, bent, and immersed in materialism. Blake, who outwardly scorned the light and color theories of Newton, was influenced by these theories more than he would ever admit. It is a happy circumstance that his passionate disavowal of Newton has bequeathed to us such paintings as "The Trilithon" in which three draped figures stand huddled together at Stonehenge while the light of the sun beats down. The figures are, of course, Bacon, Locke and Newton. Blake believed that the human sacrifices of the Druids would depopulate the earth and that they perverted the patriarchal religion.

John Russell speaks of the two paintings of Newton in *The New York Times* of Oct. 3, 1982 at the time of the "William Blake: His Art and Times" exhibition at the Yale Center for British Art:

> It is... a unique experience to see not only the famous color print of Isaac Newton from the British Museum but a radical and little-known variant of the same print that has been lent by the Lutheran Church of America in Torresdale, Philadelphia. The difference between the two is quite startling, but they do, of course, have in common the likeness of Newton himself, bent over a long scroll of paper with a pair of compasses in his left hand.

Bindman's catalogue says that one of these Newtons is at the Tate and the other in Philadelphia. The Philadelphia one is now in the Florence Foerder Tonner Collection at the Philadelphia Museum of Art. "The Trilithon" is in the Collection of Mr and Mrs Paul Mellon, Upperville, Va. All three were exhibited at the 1982 Yale exhibit and are in the Bindman catalogue. Returning to the two Newtons, Russell adds:

> At first sight this looks like a classic image of exact and inspired concentration. If only we could see as straight and think as hard as Newton does here! But the fact is that Blake did not mean us to feel like that. He meant to shown Newton as a man cut off from his own spiritual nature and engrossed in calculations of a material kind.(27H).

Newton's interest in materialism has given us two good color prints by his enemy, Blake.

Blake's writings, his literary works of art, were also very much involved with replacing Newton's system and Newton's imagination with Blake's system and Blake's imagination theory. Donald Ault, in his *Visionary Physics: Blake's Response to Newton*, includes very appropriate writings by Blake:

> Sleep on Sleep on while in your pleasant dreams
> Of Reason you may drink of Life's clear streams
> Reason and Newton they are quite two things
> For so the Swallow & the Sparrow sings
> Reason says Miracle. Newton says Doubt
> Aye that's the way to make all Nature out
> Doubt Doubt & don't believe without experiment
> That is the very thing that Jesus meant
> When is the very thing that Jesus meant
> When he said Only Believe Believe & Try
> Try Try & never mind the Reason why. (p.25)

Blake is obviously against a purely rational system. In this poem Blake is also against the *Cogito ergo sum* of Descartes which Newton subsumes. Ault also quotes Blake's statement that: "I must Create a System, or be enslav'd by another Man's: I will not Reason & Compare: my business is to Create." Blake's writings were for the most part "created" by his desire to replace the Newtonian system with the Blakean. Ault says that "Blake sees the whole history of science and mathematics converging in Newton's system in which all previous error is compounded into a unified body of error in which mathematics and science are brought together." Blake throws into the pot of contradiction not only Newton but Democritus, Plato, Aristotle and Lucretius. Blake wrote:

Mock on Mock on Voltaire Rousseau
mock on Mock on tis all in vain
You throw the sand against the wind
And the wind blows it back again
And every sand becomes a Gem

Reflected in the beams divine
Blown back they blind the mocking Eye
But still in Israels path they shine

The atoms of Democritus
And Newtons Particles of light
Are sands upon the Red sea shore ·
Where Israel tends to shine so bright.

The metaphor of science and the system of science fuse in a way to form the imaginative background of Blake's answering of Newton. Actually, it is the first paragraph in the preface to his book where Ault summarizes the relationship between Newton and Blake that is pertinent here. Ault writes:

> William Blake and Sir Isaac Newton both saw things few men see. Newton's vision was directly responsible for his immense fame and popularity as a national hero in eighteenth-century England. Blake's vision was responsible for his relative obscurity and poverty during his life. When Blake referred to himself as a "visionary" he was consciously flying in the face of a whole network of traditions thoroughly submerged in the point of view he called "Single vision & Newtons sleep" ...In this stance he opposed Newton's system of the world, even though Newton, too, was charged with having concocted a visionary model of the world.(xi)

Newton's vision caused the reaction of Blake who in his literary art created his own vision and his own system. On the other hand, this vision resulted in a materialism that Newton could not, perhaps, have imagined. Newton's theories are like a cosmic thunderbolt that will never cease its rumblings. The materialism reactions to his supposed mechanical theories have cause revolutions in science. They have also brought about great changes in the world of art. From Constable we moved to Gauguin to Cezanne, Calder, Tingueley, Miro and even to the investigations of photorealism and postmodernism. The mechanism of the camera had brought about a new science as well as a new art. We even have art that includes the sound of making it as in the case of Robert Morris's "Saw with the Sound of its own making". Ruth Nanda Anshen, in the introduction to her Credo Perspectives series writes: "The naïve view that we can observe any system and predict its behavior without altering it by the very act of observation was an unjustified extrapolation from Newton's *Celestial Mechanics.*" She says that we cannot observe man or society without interfering and that "this means, in the preservation of the identity of the knower and the known, that cognition and generation, that is, creation, though in different spheres, are nevertheless alike." James Johson Sweeney whose book *Vision and Image: A Way of Seeing* which Anshen introduces shows that this observation and interference had made creativity in the areas of the arts, specifically, poetry and painting. Sweeney, who was an art critic, curator of the Museum of Modern Art in New York, director of the Solomon R. Guggenheim Museum has consistently watched the changes in the poetic metaphor that appear in other arts. He also believes that art is "there" before science gets "there". I quote this citation in its entirety since it is so appropriate here for Newton's influence upon the arts.

> The concept of classical mechanics derived from Newton's laws had formed the foundation stones of that philosophy of materialism and determinism to which the physics of the nineteenth century seemed to have led. With their rejection "the philosophical implications of physics undergo a great change, the mechanical age has passed, both in physics and philosophy, and materialism and determinism now become open questions." (p.40).

We see this certainly in the works of literature of Darwin, *Descent*, *Origin* and *Voyage* which, as I have indicated, I consider to be works of art. After quoting Sir James Jean's Physics and Philosophy, Sweeney adds:

> And the ideal of scientific certainty as a basis for communication, which left its mark on so much painting and sculpture in the nineteenth century, had already begun to give place to an emotional emphasis with Van Gogh, Gauguin, and the Synthetist painters a decade before the publication of Planck's quanta investigations in 1899 with their philosophical consequences.(40).

It would be very interesting, and useful too, to make a study of the parallelism in science's reaction to Newton and in that of the world of art.

It seems strange that a man who was raised to divine level by others[32,33] was so maligned by Blake. Derek Gjertsen[34] says that Newton was called an "être divin" by E.L. Boullée and that Halley said he was "so near the gods man cannot go nearer." He mentions that F.C. de Blancherie wanted to start a new calendar that began in 1642, the year of Newton's birth (p.187): and then Gjertsen himself adds that "The only English figure who has excited a comparable interest and who can rank with Newton in genius is Shakespeare."(p.213).

In the last paragraphs of her book *Newton Demands the Muse* [1] Nicolson, after quoting from Blake's "Songs of Los", said that "Pope wrote the perfect epitaph for Newton: 'God said, Let Newton be!' and all was light!". Newton left this world of light, gravity, telescopes, color, mathematics and a life dedicated to science. He left it with the invocations of the Muse. He who was not interested in poetry had two great poets wave him farewell: Pope and Blake. His creative genius inspired E.L. Boullée, the architect, to create a project for a cenotaph which would include both the spirit of Newton and the light of the sun. In his *Treatise on Architecture* [35] Boullée describes this work of art and dedicates it to Isaac Newton, an architect of the cosmos.(pp.83-85).

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36. Credit to the Lutheran Church in America, the gift of Florence Foerder Tonner in memory of her dear parents, Robert H. Foerder and Caroline Fischer Foerder.

Figures

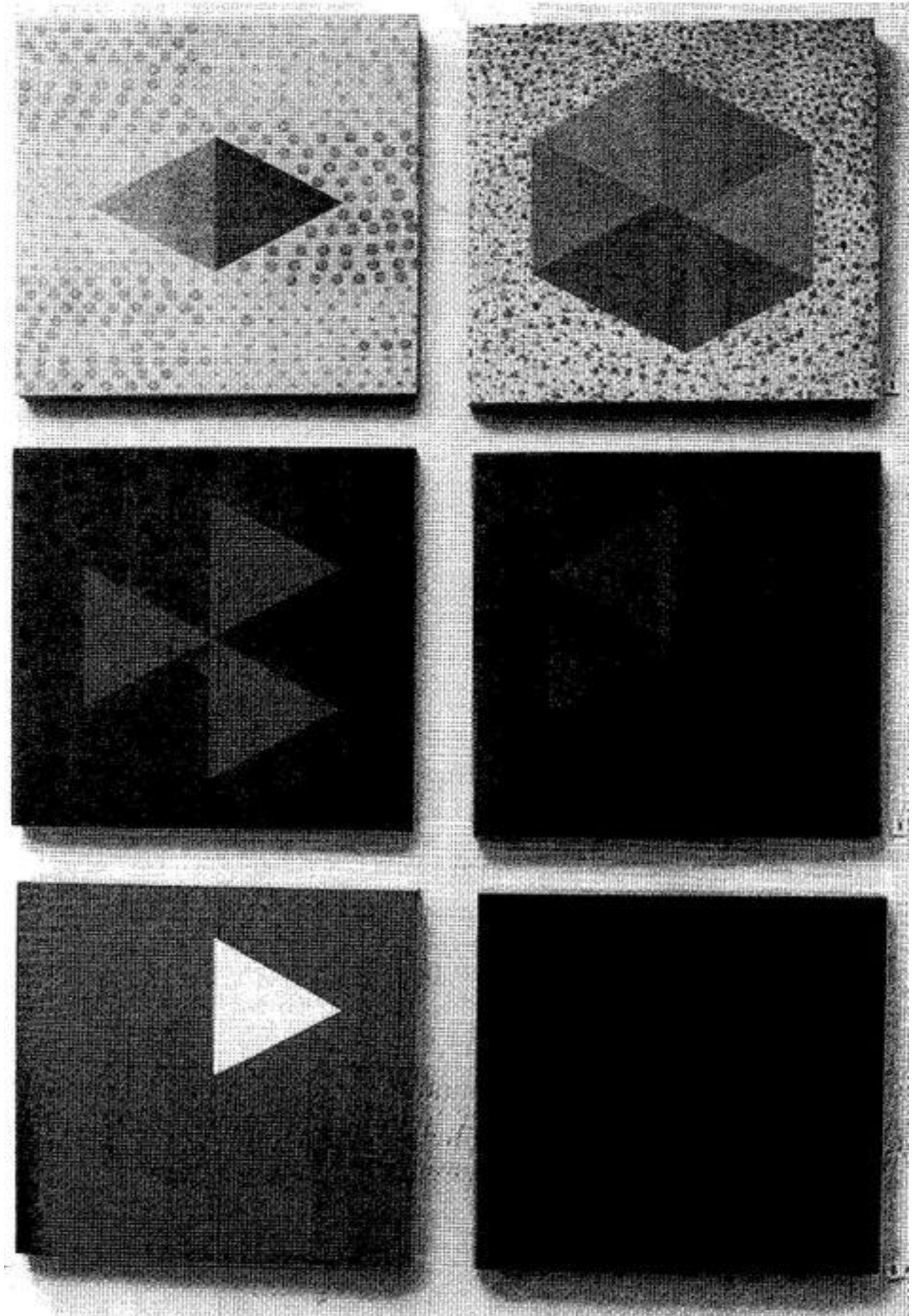


FIG 1

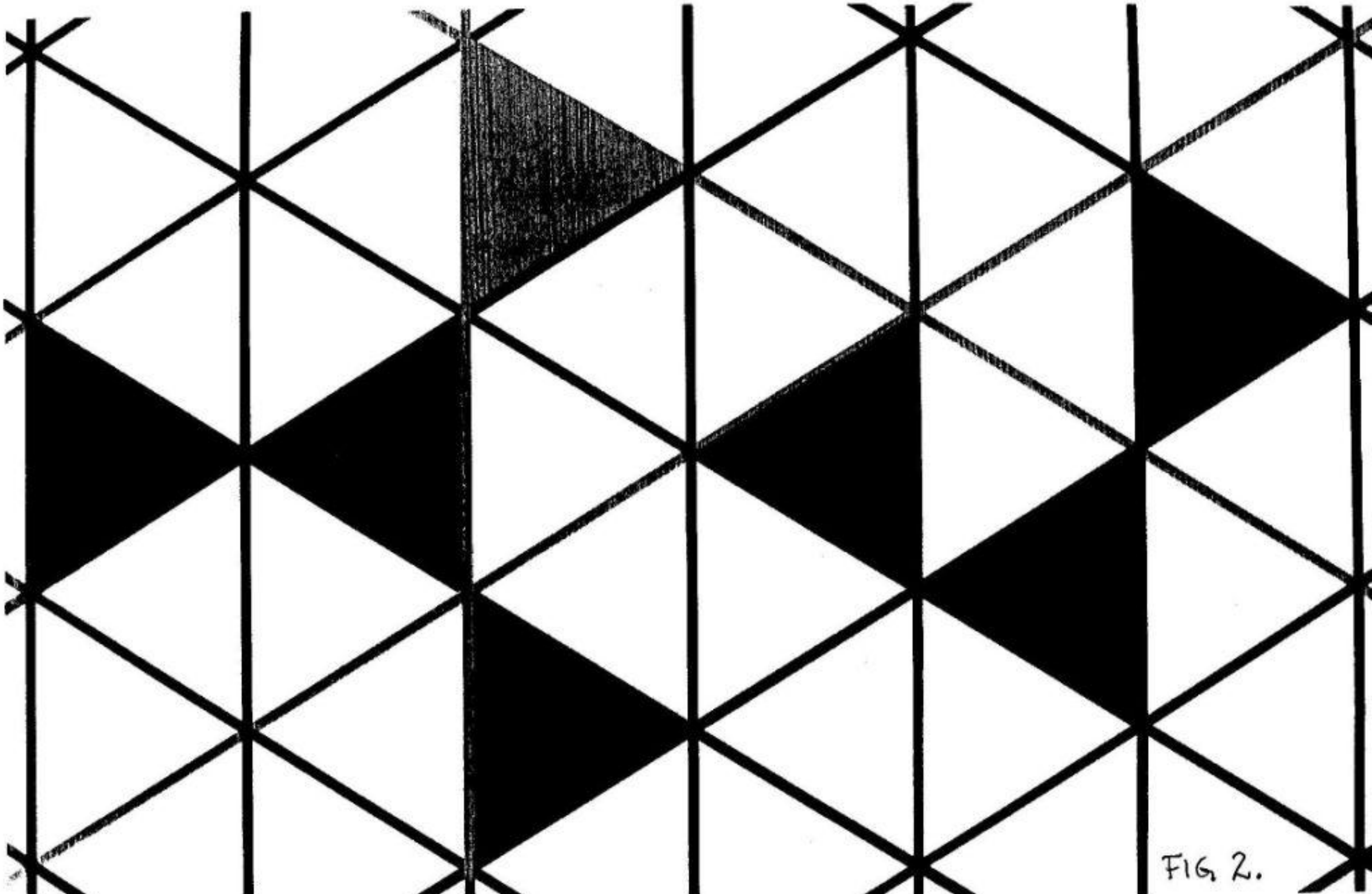


FIG. 2.

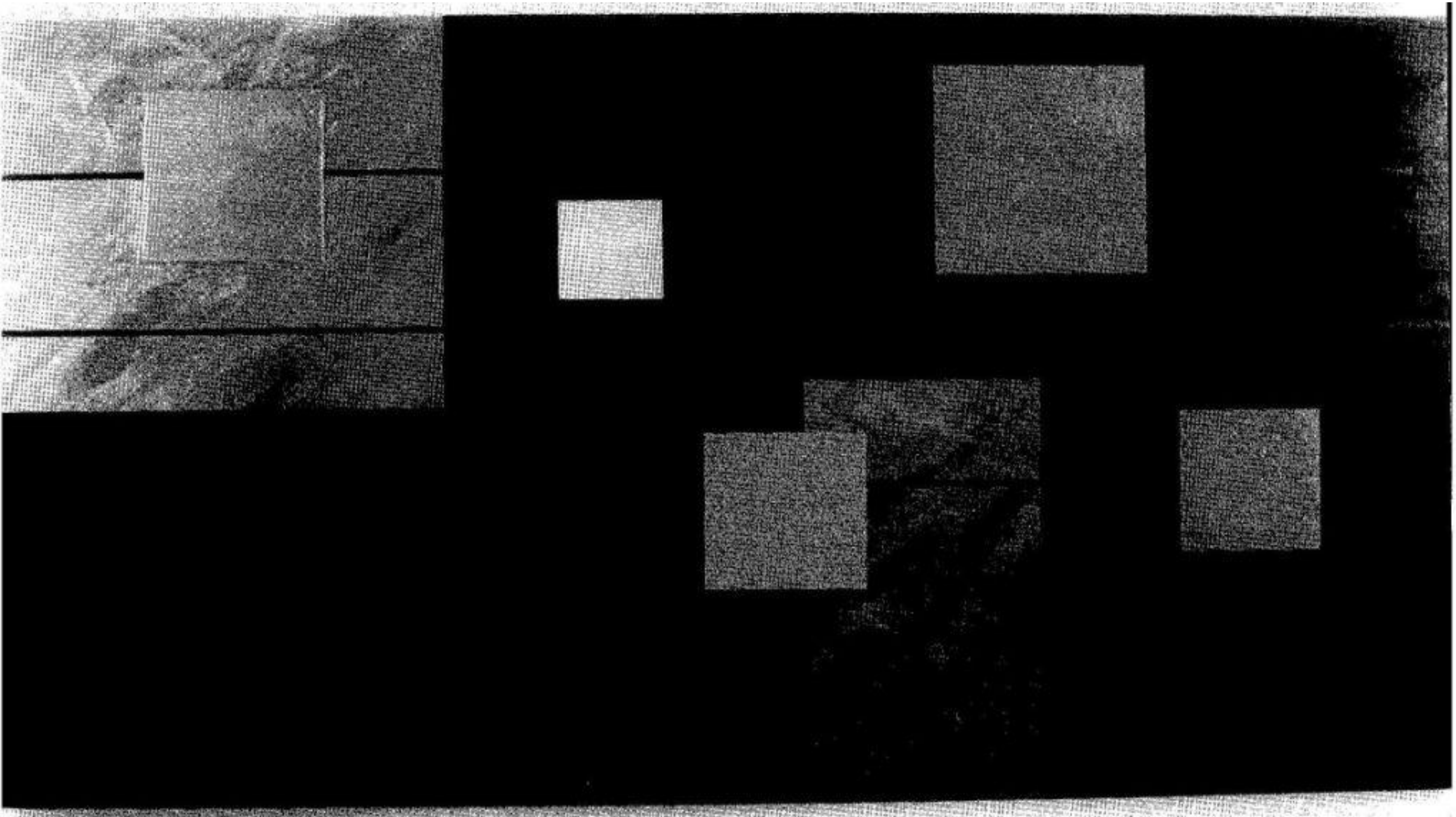


FIG 3

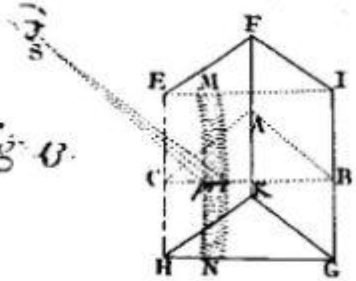


Fig: 13

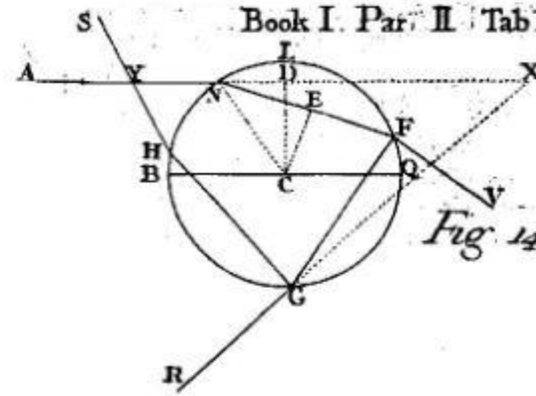


Fig: 14

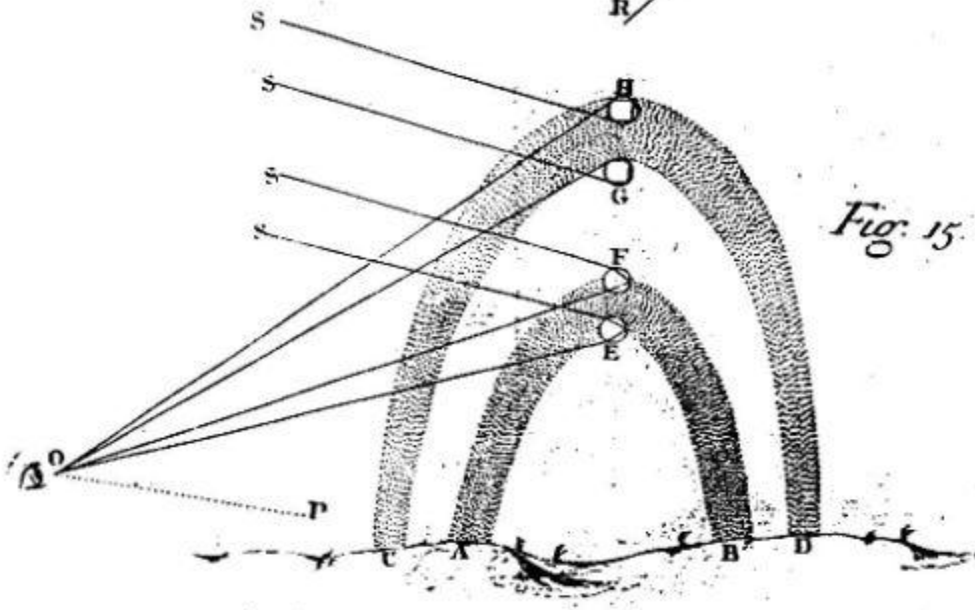


Fig: 15

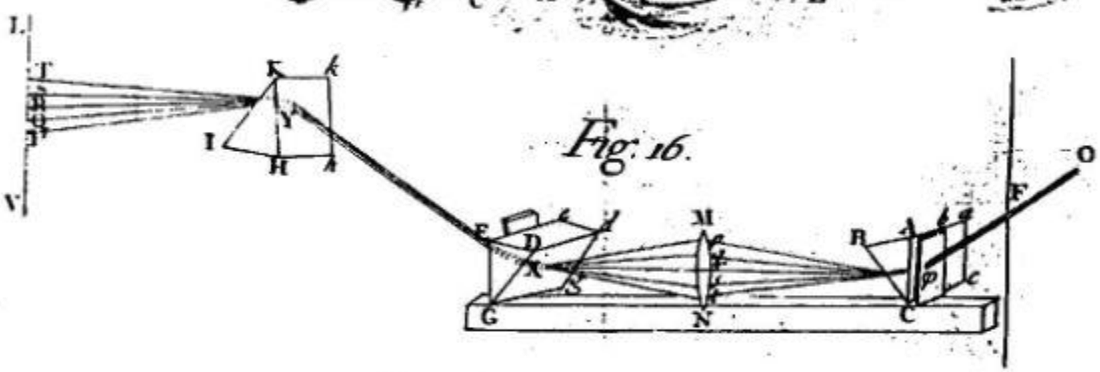


Fig: 16.

FIG 4

SIR ISAAC NEWTON.

From a Bust at the Royal Observatory, Greenwich.

London. Published Nov. 1st 1802, by H. D. Symonds Paternoster Row.

THE

MATHEMATICAL PRINCIPLES
OF
NATURAL PHILOSOPHY.

BY

SIR ISAAC NEWTON.

Translated into English

BY ANDREW MOTTE.

TO WHICH ARE ADDED,

Newton's System of the World;

A SHORT

Comment on, and Defence of, the Principia,

Ex libris J. Shanahan

BY W. EMERSON.

WITH

THE LAWS OF THE MOON'S MOTION

According to Gravity.

BY JOHN MACHIN,

Astron., Prof. at Gresh., and Sec. to the Roy. Soc.

A new Edition,

(With the LIFE of the AUTHOR; and a PORTRAIT, taken from the Bust in the Royal Observatory at Greenwich)

CAREFULLY REVISED AND CORRECTED BY

W. DAVIS,

Author of the "Treatise on Land Surveying," the "Use of the Globes," Editor of the "Mathematical Companion," &c. &c. &c.

EX LIBRIS COLS & JONES

IN THREE VOLUMES.

VOL. I.

London:
PRINTED FOR H. D. SYMONDS, NO. 20, PATERNOSTER ROW.

1803.

Printed by Knight & Compton, Middle Street, Cloth Fair.

FIG 5

Painting by Benjamin Haydon showing Newton, Voltaire and Wordsworth in the upper right quadrant (courtesy of the archires of the Archidiocese of Cincinnati).

Study for *Disks of Newton* (Etude pour *Disques de Newton*). 1911-12

Gouache on paper, 12⅝ x 9⅞" (32 x 25 cm.)

Signed l of c "Kupka"

Fédit, no. 63, repr.

Musée National d'Art Moderne, Paris (AM 2789-D)

PROVENANCE:

the artist
Eugénie Kupka
to present owner, gift, 1963

FIG 7

Disks of Newton, Study for Fugue in Two Colors (Disques de Newton, Étude pour la Fugue à deux couleurs). 1911-12

Oil on canvas, 19½ x 25⅝"
(49.5 x 65 cm.)

Dated, signed and inscribed lr
"11-12 Kupka//Etude pour la Fugue à deux couleurs"

Fédit, no. 62, repr.

Musée National d'Art Moderne,
Paris (AM 3635-P)

PROVENANCE:

the artist
Eugénie Kupka
to present owner, gift, 1959

FIG 8

Disks of Newton, Study for Fugue in Two Colors (Disques de Newton, Etude pour la Fugue à deux couleurs). 1911-12

Oil on canvas, $39\frac{1}{2} \times 29''$
(77.5 x 73.6 cm.)

Signed ll "Kupka"

Philadelphia Museum of Art, The Louise and Walter Arensberg Collection

PROVENANCE:

the artist
Walter Arensberg, 1937
to present owner

FIG 9

FIG 10

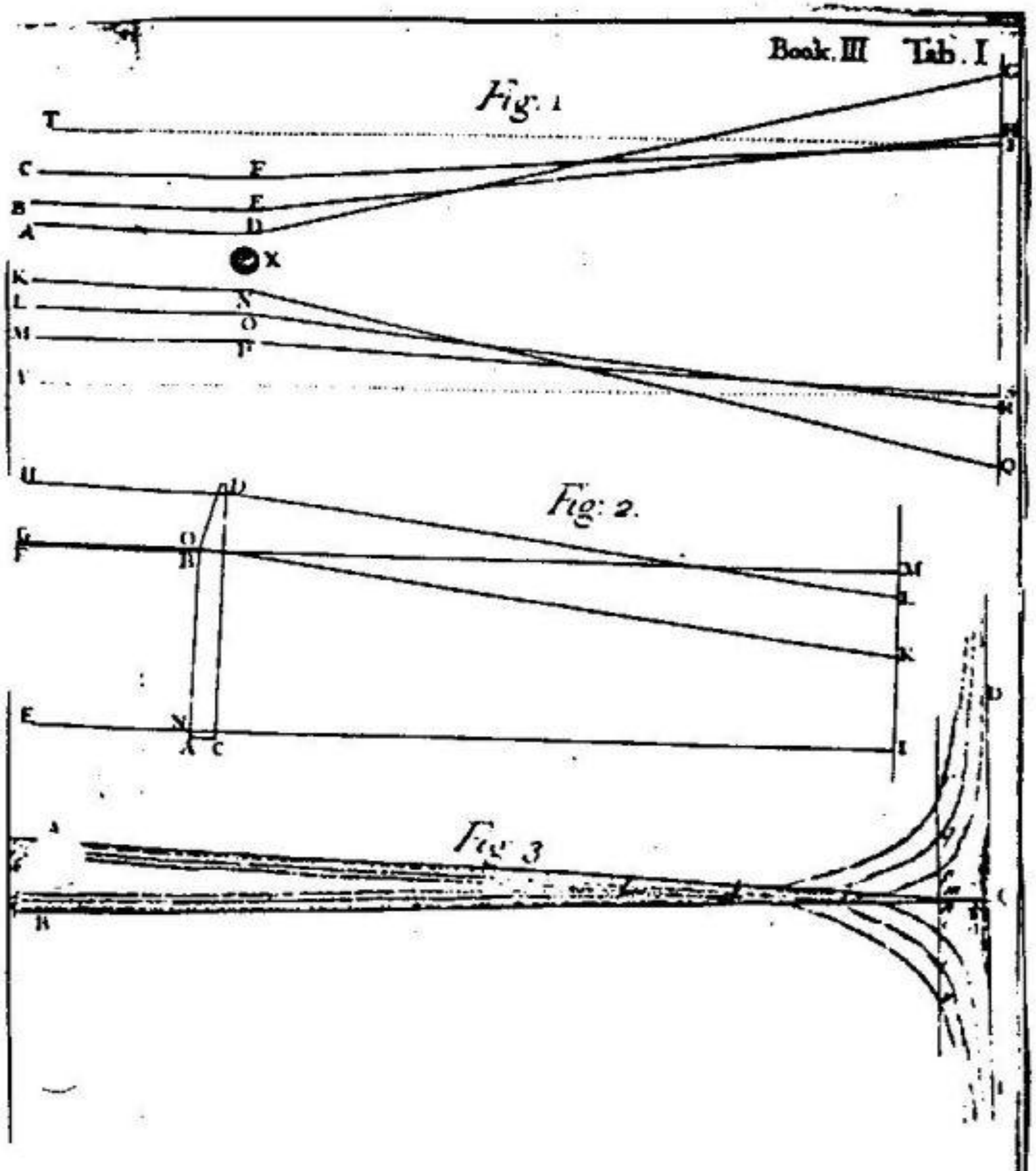


FIG 11

at the End of Vol III.

Fig 1.

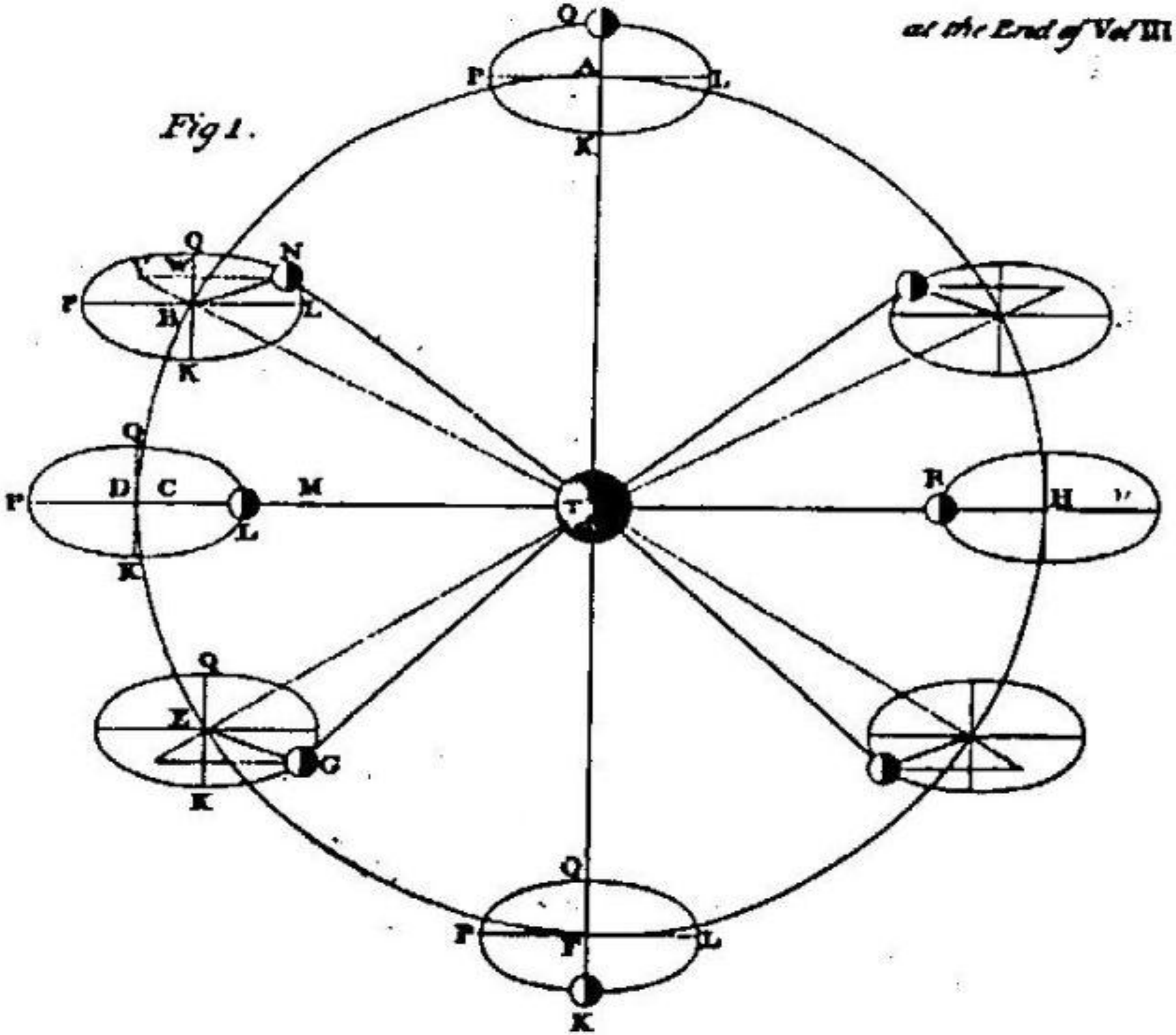


FIG 12

OPTICKS:

~~William~~ OR, A

TREATISE

~~William~~ OF THE ~~Gregory~~.

Reflections, *Refractions*,
Inflections and *Colours*

OF EX LIBRIS COLL. S. JOANNIS

LIGHT

Ex libris Joannis Shanahan

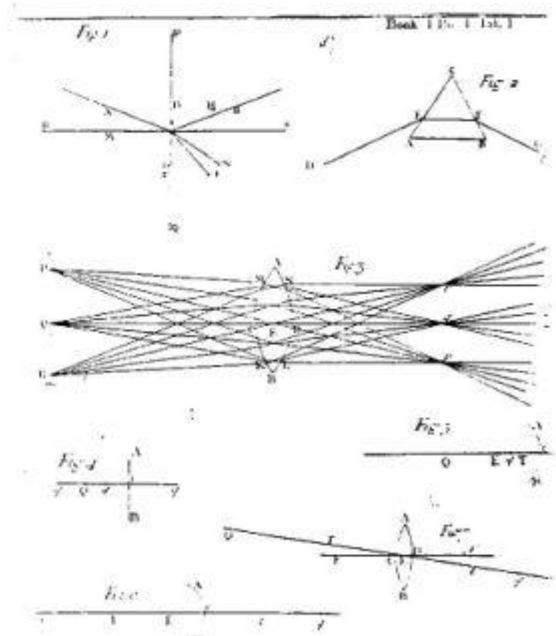
The FOURTH EDITION, *corrected*.

By Sir *ISAAC NEWTON*, Knt.

LONDON:

Printed for WILLIAM INNYS at the West-End of St. *Paul's*. MDCCXXX.

FIG 13



Newton is portrayed by William Blake

Courtesy of the Philadelphia Museum of Art, see ref. 36

Courtesy of the Tate Gallery Millbank, London

FIG 16

Many conferences and symposia were arranged during 1987 to celebrate the tercentennial of one of the greatest achievements in science, Newton's Principia.

The Lisbon symposium is probably the only one, however at which the Newtonian mechanistic paradigm was questioned by eminent scientists and scholars in such diverse fields as physics, cosmology, economics, ecology, political science and arts.