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APPLYING. THE BIOLOGICAL EVOLUTION METAPHOR TO TECHNOLOGICAL INNOVATION

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Keyword: industry; science and technology; systems analysis

THE USE OF expressions from the language of biology when dealing with innovation is not uncommon. Natural evolution was more explicitly used as a metaphor by Nelson and Winter, first in dealing with the economy and then to develop a model for technological innovation.

The natural evolution metaphor might look quite simple to a non-specialist who would mainly refer to a simplified Darwinian two-stage process—mutation (invention) and selection (innovation).

Closer analysis reveals a much more complex and conflictual situation in the realm of biology, which might be of great value when seeking to draw comparisons with the variegated analysis attempted by students of the technological innovation process. Striking parallels between the two sets of literature have been discovered.

The metaphor

When dealing with biological evolution one may refer, albeit somewhat simplistically, to three different points of view—that of the palaeontologist, of

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the biologist, and of the molecular biologist. The first, represented, for example, by Grassé, deals with understanding and explaining the phyletic evolution of the biological World. The second point of view, eg that of Dobzhanski, deals with the evolution of a single species through the study of populations. The third approach, eg in the work of Monod,⁵ seeks to understand the basic principle of biological evolution at the level of biochemistry.

These various perspectives place emphasis on different aspects of biological evolution. This might explain why, 100 years after Darwin, there is still a serious debate among students of biological evolution, with each School aggressively defending its own theories. The palaeontologist tends to emphasize the lineality of evolution, while the molecular biologist emphasizes mutation (by chance) and selection (survival of the fittest).

The search for a unifying theory has characterized the past half century of biological evolution research. We refer here to the 'synthetic theory'⁶ as representing the metaphor for the innovation process. The basic ingredients of the metaphor are the following:

- 0 a process for generating ideas or inventions characterized by creativity and chance;
- 0 a 'storage container' where inventions can be accumulated;
- 0 a 'duct with an on-off valve' which connects invention storage to the selection device;
- 0 a 'selection machine' to test the inventions, accepting only those which are fitted to the 'environment'.

With respect to a simplistic 'change and necessity' theory, there are two major differences. First, the ultimate fate of an invention is not decided at the moment when it first appears, so future, more favourable conditions could govern the selection process. Second, the state of the valve (open or closed) is governed by a complex feedback mechanism that is dependent on past events. This is due to the architectural constraints imposed by the 'solution' already developed (the biological individual or the product and its related manufacturing process) that the invention aims at modifying.

These two ingredients in the model (storage and the go-no-go valve) are responsible for some of the most interesting features that appear to be characteristics of both biological evolution and technological innovation—the existence of a 'preferred path' of evolution (a chreod or necessary path according to Waddington) and of different speeds of evolution in different times and conditions.

The existence of a different era of accelerated and large innovations in the period of phyletic change followed by a period of exploitation of the 'basic' invention is best expressed by Grassé.⁸

In studying *Drosophila* populations genetic changes appear to diffuse in filling an ecological niche, with the characteristic features of a logistic curve.

Mutation in DNA cannot be fruitful unless in the cytoplasm the proper enzyme is available that can 'read' the new words formed in the genetic code. When, following a completely different chain of events at organic and glandular levels, new enzymes are produced, then a stored unused mutation in the DNA could produce sudden important changes. 10

The Russian puppets model

Koestler presents his theory of the 'holon'¹¹ in a way reminiscent of Russian puppets. He uses the word *holon* to mean a unitarian and complex system. At a certain level of observation of the world, one can view it as a holon. At a more detailed level of analysis one sees a holon at each level of analysis. The same happens if one goes up in the level of aggregation. The resulting global image of the world is therefore that of an infinite set of holons, one included in the other. The dream of breaking down our view of the world into elementary components (the reductionist's approach) seems, at the least, impracticable.

Referring to biological evolution, the view put forward by Koestler seems to apply: at a certain level of aggregation (at the palaeontological, or biological, or molecular biological level), one can look at the observed data as manifesting systemic behaviour. The fact that each holon shows the same basic dynamic characteristics, might simply be a 'topological' characteristic of open systems.¹²

We now consider to what extent the Russian puppets model also applies to technological innovation, a process that encompasses very different levels of world view—from fundamental science, to applied research, to development and industrialization. To emphasize a certain correspondence (although it is not an essential point) with the three levels of aggregation presented for the case of biological evolution, we refer here to three levels of aggregation when examining technological innovation:

- the epistemological perspective such as that of Kuhn;¹³
- the perspective of the diffusion of innovation, as typified recently by the work of Marchetti;¹⁴
- the macroeconomic viewpoint such as that of Freeman,¹⁵ and Abernathy and Utterback¹⁶ in the study of long-term innovation change in industrial sectors.

As we try to show, the theories put forward to explain the basic facts analysed in each of the three vantage points are consistent with the basic metaphor described above.

Popper's theory of conjectures and refutations¹⁷ (focusing on the holon of the individual scientist) parallels that of a simple 'chance and necessity' Darwinism. Kuhn,¹⁸ with his concept of 'normal' science, placed emphasis on the 'architectural' constraint of history which seems to force the search along preferred paths. We refer below to the contribution of Feyerabend.¹⁹

The success of 'substitution analysis',²⁰ when applied to so many different sets of data, can be interpreted with the same model used by biologists in studying the diffusion of a best fitted population in an ecological niche. The three-stage model²¹ used to interpret the technological change of an industrial sector (from a state of flux when product innovation prevails in the search for a successful design, to a maturity phase where incremental process innovation prevails) looks very similar to Grassé's²² model of phyletic evolution.

The catastrophe model

The dynamics of a closed system are governed by the increase of the entropy. Open systems on the other hand, in their input-output interaction with the

environment, tend to increase the varieties of their **configurations** and their complexity to the point where through a crisis or a catastrophe a new systemic **structure is produced** (order from **disorder**).²³

The simplistic model of an open system described above using the biological evolution metaphor, can explain the dynamics of the system between **one** crisis and another. The selection mechanism ensures that the system keeps itself in 'equilibrium' with the environment after it has adapted to it. The effect of the reservoir is a **strategic one**—in other words, being prepared for changes in the environment. The biologist, to underline **these** two abilities of a **biological** system, distinguishes between 'normalizing selection' (the tactical ability to maintain the system's aptness to the environment notwithstanding the push to **change coming** from mutations), from a 'directional or balancing selection' (the **strategic** ability to keep the system's fitness in **line** with the changing environment, taking advantage of the stored mutations).

This model, however, does not explain sudden 'catastrophic' changes. The literature of **biological** evolution can help further in pursuing the metaphor application to technological innovations. At the palaeontologist's level of aggregation, phyletic evolution has presented four or **five** big 'revolutionary' changes. In **each one** of **these** crises a 'mother form' appears from which various phyla develop. Some phyla go through a specialization **process** and evolution might come to an end, either with the **species** maintaining a **static** equilibrium with the environment, or with the disappearance of the **species**.²⁴ Other phyla maintain more archaic characteristics, develop less specialization and also take on new characteristics seemingly of no use for the **species** itself (eg mammalian characteristics in reptiles), up to the moment when they converge in a new 'mother form'.

Increasing complexity in body organization and in the level of **brain development** characterizes the changes from **one** stage of phyletic evolution to the other. '**Progress**' in nature seems therefore to **have** a precise characterization: the ability to manage increasingly complex structures by means of an increasing ability to **process** information (higher **mind**).²⁵

At the biologist's level of aggregation, the appearance of a new **species** (speciation) is the equivalent of crisis **change**. How may speciation be explained? Are new **species** generated by a continuous **process** of **change** (anagenesis) or by a sudden **change process** (cladogenesis)? Three of the mechanisms posited to explain **cladogenesis**²⁶ might be important for our metaphor:

- Isolation of the environment (the dumb-bell **principle**). A population of a given **species** living in an environment which separates from the rest (eg after a tectonic **movement**)—and stays thereafter completely isolated from other populations—might develop into a new **species**.
- Transplanting pregnant females into a new environment (the **founder principle**). Their progeny **could** develop into a population in which the selection of stored **genetic** changes **fitted** to the new environment might result in a new **species**.
- Hybridization among **close species**, living in overlapping ecological niches.

The **first** case refers to the effect of the construction of different environmental

histories-open systems interaction; and the **second** case refers to exploitation of the potentiality for changes stored in the reservoir in case of a sudden environmental **change**. The third refers to interaction among separated open systems to form a new **one**.

It is interesting to use the metaphor to **find** analogies in epistemology. Feyerabend's²⁷ contribution to epistemology is that of revindicating the role of the 'anarchist' scientist who, by following an unconventional search path, **produces** new ideas (experimental data and theories). To do this he has to *isolate himself from the prevailing environment* of 'normal science' (to **behave as an** anarchist). The build-up of the new ideas together with the increasing inability of normal science to explain **accumulated** experimental data, might result in a new theory (a new Kuhnian paradigm).

An analogy with the **founder principle** (but also with the importance of carrying forward archaic characteristics in phyletic evolution to produce a new 'mother **form**'), might be found in the **procedures** by which a designer operates. In approaching a new problem to be solved, he **first** makes a perusal of past solutions to both similar and different **problems**.²⁸ Making old ideas work in a new set of **specifications** sometimes results in successful new **products**.²⁹ It is also interesting how often philosophers, in their search for truth, revisit ancient philosophical theories (eg revivals of **Eleatic** studies by neo-positivists) to **find** new starting points. With respect to the hybridization model, it is interesting to explore its relevance in the progress of science and technology through the overlapping and **convergence** of separate **disciplines** into new **fields** such as bio-engineering, physical chemistry, etc.

Long-term changes in technological innovation

It is naive for electrical engineers to state that complex systems demonstrate oscillating dynamic behaviour, because of the complexity of their feedback correlations and the imperfections of their 'control and instrumentation' system. Industrial dynamics³⁰ **have** helped to transfer this **basic** understanding to the **economic** and **social** systems. When trying to set up a simulation model of a complex system, the **need** for simplification **compels one** to distinguish between internal and exogenous variables, and to look for the determinants of changes.

Changing the way this subdivision is **done** in the model brings about **differing** explanations for the cause-effect relationships. The debate is clearly apparent when dealing with the issue of long-term **economic change**.³¹ It is suggested here that any *complex open system* shows intrinsically a dynamic behaviour that goes through a series of expansions of a **logistic** type followed by catastrophic changes. The interactions between different complex systems (holons?), or, more simply, between a system and the 'rest of the **world**' (the environment), determine the timescale between **one crisis** and another. The Russian puppets model and the interactions *up and down* between the different holons **could** help to understand the appearance of micro- and macro-cycles and hypercycles.

It is not our intention to pursue this **line** of thought further. We simply point out that it is not strange at all, when **one** focuses the analysis on the techno-

logical system, to discover intrinsic sagging-type dynamics. Analysis of major invention-innovation data is consistent with the metaphor put forward at the beginning of this paper. The storage mechanism in particular is clearly evident.³² That the interactions between different holons are important in setting the time constants of the global system, can be seen for instance in the analysis by Marchetti.³³

The scarcity of data on technological inventions and innovations, and the ample margin of discretion in their classification, leave plenty of room for debate when trying to define quantitatively the characteristics of cycles (eg are waves of a constant length or not; how many cycles have there been since the beginning of the industrial revolution?).

To what extent does the metaphor that we are proposing help? We have already obtained hints on how the speciation metaphor can explain changes in the paradigms within the basic science holon. What about the interactions among the different holons internal to the innovation process (basic research, applied research, development)? Giarini and Loubergé³⁴ have proposed an interpretation of the past 200 years of economic development in terms of two major waves—the first is a technological wave based on the build-up and exploitation of empirical knowledge developed in the 18th century, and the second is a wave based on the interaction between technology and science starting in the last part of the 19th century.

Industrial sectors

One could interpret the second wave proposed by Giarini and Loubergé as a speciation deriving from the hybridization of overlapping 'species' (science and technology). For the heuristic use of our metaphor we propose a more disaggregated analysis, at the level of the industrial sector. At the beginning of the industrial revolution all industrial sectors were based on empirical knowledge and their development could be viewed on the basis of the invention-storage-selection model internal to the holon of development and industrialization. The development of modern mechanics and thermodynamics has certainly helped the development of technological innovation, but in a somewhat indirect way (a positivist philosophical posture, an understanding of the basic principles and constraints from science, etc).

The thermo-mechanical sectors have so far developed mainly on the basis of empirical knowledge. Other industrial sectors have instead developed following a different pattern, *viz* the 'science-based' industrial sectors (such as the electrical and chemical industries). Scientific knowledge developed first; the related industrial development can be seen as the exploitation of the niche opened up by the scientific discoveries.

The relationship between science and technological development has been very strict. The history of the development of large companies in the electrical sector, eg General Electric, or in the chemical sector, shows the pushing role of basic and applied research. The fact that these sectors were based on scientific knowledge had an important effect: their technological development 'path' could be forecasted following the scientific discoveries and progress. The similarity with the threads of the biological metaphor is apparent. The 'ecological niches' of these sectors seem now to be well exploited, and several

authors³⁵ point to the 'law of diminishing returns' of research in such fields.

The position and the **role** of research in the empirically based sectors are different. Applied research here has mainly had a 'service' **role** in solving problems posed by the practical development of the **sector** itself. Direct coupling with basic research has been **scarce**.³⁶ What will happen when the empirically based sectors 'encounter' the basic science, and **scientific** knowledge could then be used to design a product (predicting theoretically its detailed behaviour without having empirically to test prototypes)? This might be the beginning of a new chreod of development, a speciation by hybridization of different **cultures**. **There** are signs that this is becoming a reality for very complex products such as vehicle engines.

The reservoirs of basic and applied research—**filled** up with inventions that **have** led to innovations in other sectors—will be available to exploit the new innovation needs, as soon as the 'selection valve' on the ducts connecting them to the empirically based sectors opens. The limitations of the empirical approach for complex product design **have** until now enabled the attainment of only 'satisficing' design compromises. The scientific approach will enable **real** optimization in meeting design **specifications** and constraints. How far is today's 'good enough' car engine design (which developed through a century of empirically based invention and innovation) from tomorrow's **optimal** design (based on the possibility, for **instance**, of predicting on paper the distribution of flow **fields** and of materials composition in every part of a combustion chamber)?

While existing **scientific-based** industrial sectors are approaching the exhaustion of the exploitation of their respective chreods, the old, mature, empirically based sectors might be **faced** with a lengthy **period** of new development. The actual situation is more **complicated** because we are **facing** not only hybridization between empirically technological and basic knowledge, but also hybridization with 'horizontal' new technologies such as microelectronics and informatics.

The **coarse** picture of technological innovation that emerges above at an aggregated **macroeconomic** level is that of a superimposition of the somewhat separated development of two different **classes** of industrial sectors: **one** development **started** from the holon of industrialization, and the other from the holon of basic science. It might be interesting to speculate whether **there** has been a third chreod of development for new sectors starting within the holon of applied research.

Without going too far into this **topic** could **one** not look at the phenomenon of the large applied research projects **started** during world war 2 (radar, nuclear energy) and soon after-(space) from this point of view? **These** projects certainly may **have started** because of existing **consolidated** scientific knowledge (successfully passing the selection test in the basic research holon) pointing to potential practical application (**filling** the applied research reservoir of inventions). The establishment of large projects has had the effect of opening the selection valve and providing resources to **perform** the selection operation itself. It can be viewed as a speciation emerging from a 'pregnant' applied research 'female' transplanted to a new environment (the resources made available by the big projects).

Will these new phyla given birth by the 'mother form' 'of applied research develop into successful new industrial sectors (species)? The fate of the nuclear industry is in doubt but space telecommunications, eg, seems here to stay.

Time phasing of industrial innovations

In another paper,³⁷ this author has used the biological innovation metaphor to illustrate how the relationships within an enterprise develop between R and D and other functions within a Company, and whether a rational approach could be followed in the subdivision of the financial resources between the different investment needs.

In a large Company, manufacturing, design and applied research can each be considered as a complex open system-separated organizationally and spatially from each other-displaying its own 'evolutionary' dynamics, with complex interactions among themselves and with the environment (see Figure 1 where the case of three interacting invention-selection systems is shown forming the innovation process, from basic to applied research, to development and industrialization).

The intrinsic 'time constant' is different for the different stages in the innovation chain. For instance, in the case of the car industry, the lifetime of an engine factory is of the order of 20-30 years, that of an assembly line is around ten years. The commercial lifetime of a new car model is around ten

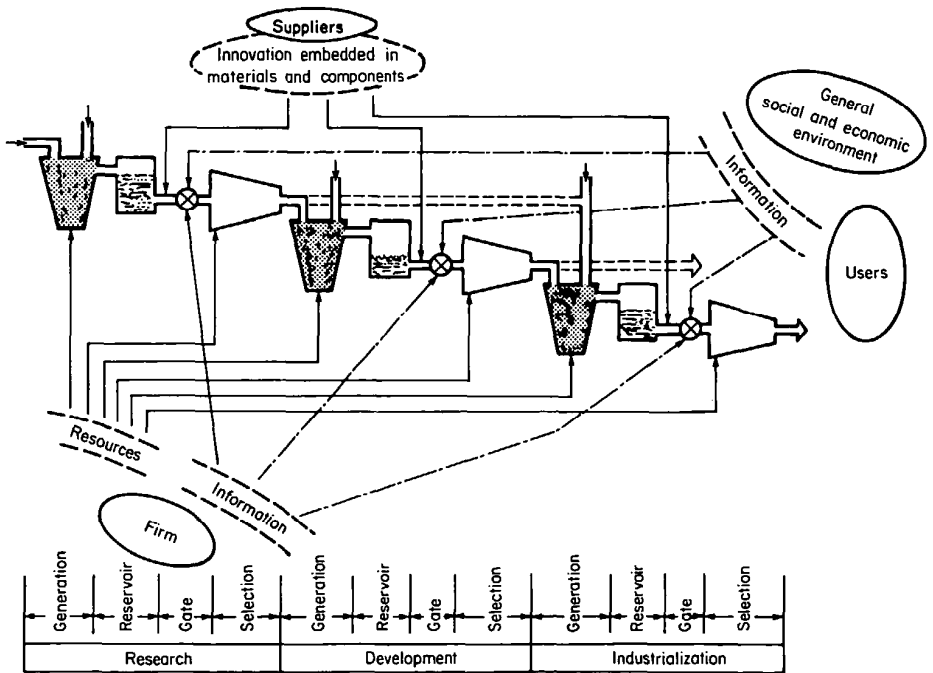


Figure 1. The inter-related open system of the Company

years, with two to three major restylings during the model life. The time needed to design a new car, assuming that **all** the relevant technical and technological information is already available, is four to five years. **Demonstrating** that a new engine **concept** is feasible, or that new materials can be technically and economically **introduced** on cars, can range from a few years to 10–20 years. The **difference** in time **constants** and the uncertainties intrinsic to R and D projects show how important it is to **have** the reservoirs of invention in the development and industrialization system well **filled** at the moment when the **decision** is taken to proceed with a new product design and new **capital** equipment investments.

On the other hand, the successful completion of an applied research phase showing how to **change** innovatively a product **component** cannot be **transferred** before a **decision** is taken to **change** the product model or to **renew** the obsolete manufacturing equipment (the selection valve should be open).

According to our metaphor it is to be expected that the flux of actual **innovation** (the output at the end of the innovation **chain**) will display oscillatory behaviour. Do **these** oscillations **have** wave-like characteristics with **constant** periods? The theory of product life-cycle assumes that products, in a **certain** product **class**, **have** a distinct **constant** lifetime. In **recent** years, however, this theory has been **much** criticized, and only in special **cases** (a mature industry, a stable market) a periodicity is apparent (eg in the case of automobiles in the USA in the years 1950-60).

More common are non-periodic oscillations. The Company management is directly responsible for setting the time of **each** innovation oscillation because of the **decision** to start a new product and/or to **renovate** the **capital** investment. The intensity of the innovation in the new product depends, however, less directly on the management itself, because of the effect of previous **decisions** on giving resources to research projects (opening the selection valves in the R and D system) and the availability of innovation proposals from outside the Company (suppliers of materials and equipments), etc.

When aggregating individual companies in an industrial **sector**, and different sectors in the **entire** **productive** system, it seems **difficult** to accept that the aggregation of widely different unphased and unperiodic oscillations will **lead** to a **periodic** behaviour. Even the clustering of major innovation seems **difficult** to understand in terms of aggregating the **microscopic** behaviour of the different actors of the innovation **process**. The contradiction with the **evidence** of large innovation **changes** within an industrial **sector** (see eg Abernathy's study of the US car **system**³⁸) might simply be another example of the **reductionist** approach in complex systems analysis being invalid (the system displays global behaviour that is different from that of the sum of its **components**).

Environmental change

The **biological** evolution metaphor, and especially the **reference** to speciation mechanisms, **could** help in understanding better how **change** in the **environment** **could** be related to a sudden burst of innovation.

Let us suppose that a major **economic crisis** is the equivalent of an **environmental change** in natural evolution. What happens at the micro-level of a Company when a sustained **crisis** is occurring? **Each** individual Company,

because of the gloomy market forecast, will try to delay the introduction of new models **and renewal** of the manufacturing plants whose planned time of **change** falls within the **period** of **economic** crisis. Notwithstanding this, the old product has to **sustain** the competition which is becoming stronger due to market shrinkage. Company management is therefore looking for innovation which can reduce manufacturing **costs** and to some degree **renovate** the old product (a restyling or facelift?) at as low a **cost** as possible. The innovation, mainly at the component level, should be compatible with the existing product and the current manufacturing system.

Within **these** constraints, the management is ready to take higher risks, to some extent accepting not fully proven innovations. In the jargon of our metaphor, the selection valve is now open. During an extended crisis, **therefore**, the selection **machine** operates at the component level, and the **entire** industry **structure** has an opportunity to learn, directly in the **field**, how to make the best use of innovation. In other words the formal barrier between research and industrialization is raised and the two systems proceed together **along** the learning process.

When the **economic** crisis is over, the diffusion of the acquired learning, at the component level, within **all** the Company functions, of how the innovative **changes** can be **dealt** with, will **provide** the starting point for innovative jumps, this time at the **system** level (both product and manufacturing being considered as a system). To give an example, the introduction of a microcomputer as a trip computer on **cars**, mainly as a way of giving a **facelift** to the old product, will introduce electronics to the **mechanical** world of car engineers and **provide** a degree of **familiarity**; this learning will thus **provide** the basis for a true integration of electronics and mechanics when designing new engines.

As another example, the introduction of automated computerized quality control stations at different points in car manufacturing lines might be **accelerated**, in a time of crisis, because they are compatible with existing manufacturing facilities, they increase quality, and reduce **cost**. The experience thus built up will enable, when a completely new plant is being designed, **changes** to be made in the **entire** systems philosophy interconnecting, via computer, **all** the automated quality control stations; with such automation feedback, signals may thus be obtained which will enable **changes** to be made in the **process** variables (for **instance** changing the dies or tools) in order to keep quality within prescribed ranges.

The future of the world of products

When analysing natural evolution, it is difficult to resist the **temptation**—following the apparent **finality** of the evolution itself—to **forecast** what will be the next step. Teilhard de **Chardin**³⁹ attempted this. The pervasive diffusion of information technology—with the exponential increase in the flow of **communications**, and the building of memories external to our brains—might be seen as a move in the direction of the development of the **nous**, forecasted by Teilhard de Chardin. Further, a **recent book**⁴⁰ suggests that increasing data available on the **mental** activity of different animals might point to the direction of evolution focused on developing the **optimal brain**.

The reason for mentioning Teilhard de Chardin and his epigons here—acknowledging their **much** more ambitious and far-reaching **work**—serves to **raise** the following question: is it possible, on the basis of the *process* of evolution (not its ends but its means), to **forecast** the lines of development of products made by man? Technological innovation (in its broadest meaning) is the process (the means) used to **renovate** the world of products. It might seem easier here, with respect to the natural evolution case, to accept that the end (the *finality*) of the progress in the world of products is **clear**, *viz* to satisfy, in an increasingly better way, human needs. But is it? **How** do human needs change in the light of the appearance of new products?

Fortunately, it is not **necessary** to examine the *finality* of **product development**. The general process itself by which an open system interacts with the environment seems to condemn it to progress in a **certain** direction, following a typical pattern. An open system that emerges renovated in its **structure** after a revolutionary change (a *catastroph.e*) exploits the potential of its new **structure** (it **fills** its **ecological niche**), increasing its complexity (both internal to the system and in relation to the environment) to a point where it requires increased capability to **deal** with such complexity. A revolutionary change might then occur, which will change the systemic **structure** and the system's relationship with the environment .

The **Grassé**⁴¹ definition of progress in phylogenetic natural evolution (increasing complexity, 'controlled' by an increased level of **mental ability**), could be translated as a metaphor to the world of products by substituting the notion of **mental ability** with 'information' or 'knowledge'. It is not **difficult**, when looking at human history, to **trace** the continuous increase in the knowledge needed to manufacture **and/or** use products. The simple case of the **vase** proves the point. In prehistoric times, **clay** and solar heat were used to make pottery. The amount of information needed to learn the manufacturing process was low. It was then learned how to make vases out of glass: the information needed to learn this process was **much** higher. Referring **now** to a **vase** made from thermoplastic material, a great amount of information has had to be **accumulated** (**organic chemistry** to develop new materials, manufacturing technology, etc) in the past two centuries to make this possible.

Luckily, **one** has not had to use **all** that **accumulated** information (studying chemistry, thermodynamics, control theory, etc) to make a **plastic vase**. The information has been aggregated in easy-to-use 'packages' (the thermoplastic grains, the extrusion **press**, etc) so that, because of this high degree of **order**,⁴² it is very simple to transfer the required knowledge to the practical manufacture of plastic vases.

Forecasting product changes

The method we are suggesting here in trying to **forecast** **revolutionary changes** in our world of products (revolutions, which might be **difficult** to detect because they are masked by the continuous **incremental** innovation both in products and manufacturing process), is, to look at the increasing degree of complexity (in different **product sectors**, **and/or** looking from the perspective of different **societal** functions), and ask oneself if in dealing with such complexity a new 'order' might not be needed and made possible because of a higher-level ability

to aggregate and manage information. It is suggested here that the problem be examined from three vantage points: that of the *materials* needed to manufacture products, that of the *primary human needs* satisfied by the products, and that of the so-called *service sectors*.

Materials. The number of different materials available to build any kind of product has increased 'exponentially'. Even a **talented** mechanical engineer has difficulties in perceiving the relative **advantages/disadvantages** of a host of engineering **plastics**, for example. Different materials are **first** adopted and then discarded in new models of a product, to reappear (often together with a new manufacturing **process**) in later versions of the **same** product. The **successful** application of new materials in **one** industrial sector (eg carbon **composites** in aircraft) is pushing designers to look at the possibility of their use in completely different **fields** (eg electric motors, **cars** etc). The learning **process** for **optimal** use of new materials goes through a phase of trial and error, and it is very long-thy: it took more than 15 years from the first appearance of **thermo**-plastics in car panel boards to its **optimal** use today (both from the point of view of design style, **choice** of materials, and manufacturing **process**).

The **first** wave of industrial revolution was dominated by steel as the base material for most industrial products. **Since** then, new materials **have** been added to the list, at an **accelerated** pace in the past half century thanks to developments in chemistry. Fibre composite materials, together with new **process** technology developed to increase the flexibility of application, might well become the new base materials. If so, the product design itself (and possibly the way products perform their **basic** functions) will be changed. Today's subdivisions between industrial sectors (primary materials producers, the materials processing industry, and the **component** and end-product manufacturers) will **have** to **change** in such a case.

The amount of information needed to design and manufacture products using composite materials at their optimum, is certainly greater than that for using steel. The problem (in our metaphor, the problem for progress) is to establish whether such increased information could be managed to simplify the entire process of designing, building and using products.

Primary needs. To oversimplify, one could say that products can be grouped according to the primary human functions they satisfy—the home, transport, food, etc. The primary needs, however, do interact among themselves, to a higher or lesser degree case by case. **Product** specifications should therefore take account of such interactions. The **basic** design of a product and the way it **satisfies** the **basic** need—and takes care of other needs—might, however, **have** remained unchanged over several **decades** or even **centuries** (even if the product and its manufacturing technology **have** undergone a continuous series of **innovations**).

In the meantime, from the **first** appearance of a product society might have changed greatly and **hence** the way the primary functions interact. **Is** the base design of the product (conceived years ago and at that time, hopefully, optimizing the satisfaction of human needs) still then the **optimal** response?

As an example, consider kitchenware. The number of products has

increased enormously, and often they **remain** unused in the kitchen which has become increasingly small, especially in the dense urban areas. Patterns of food consumption are also changing with a growth in the variety of foods available (from **all** over the World), and the types of processing (raw, **pre-cooked**, frozen, etc). Today's **consumer** is confronted with many alternatives, from the traditional family **recipe**, to fast microwave cooking, to frozen TV dinners. Has the position not now become too complex and too great a **contrast** with the changes in other primary needs (**home**, leisure, etc)? A reappraisal of kitchenware goods to simplify (with a higher-level use of available information) the situation might be needed. This might signify **quite** a 'revolutionary' **change** in the **product world**.

As another example, in the **same vein**, take the interaction of the automobile with urban **traffic**. **One solution** proposed by transport planners years ago, but apparently with little or no **success**, was to induce a shift in the use of the different modes of transport, favouring the increased use of **collective** public transportation. The resistance of car drivers to abandoning their **habits**, notwithstanding the increasing complexity and **reduced efficiency** of modern driving (slower **average** speeds, parking problems, etc) should point to a new direction, which might **lead** to a 'revolutionary **product change**'. Here **again** the answer might lay in making use of higher-level information management, thanks to the information technology revolution. The new car of the future will then be **one** having the capability of interacting actively with a computerized **traffic** control system, not only to optimize the operation of **traffic** lights, but also to **change** modes of driving (to an automatic mode) on **certain** properly instrumented lanes.

It might be too limited, though, to look at 'revolutionary changes' in **auto-**mobiles by **considering** merely the interaction with urban **traffic**. The interaction with parking, for **instance**, as well as with other short- and long-distance transport needs are important, and, taken together, might **lead** to a complete **redesign** of transport means and infrastructures. In this **specific** case I am not **indicating** a 'hard **change**'. The constraints derived from historical **develop-**ments so far (with **all** the patterns of 'hard' investment already made) preclude such a 'hard' **change**.

Hopefully, smarter use of 'soft' technology at the car design stage (for **instance** the **length** of a car, better matching requirements for parking and car transport by rail) and for improved use of existing **infrastructure** ('intelligent' **traffic** lights, instrumented lanes, etc), might **achieve** a lot. In the end, a big revolutionary **change** (a simpler way of managing a dense and highly mobile society) might result. Nature, to **change** from primates to man, did not rebuild the body, but simply added a small **cortex** to the **brain**!

Services. The third case derives from the **service** sectors. An increasing share of the **active** population is working in the tertiary **sector**, and **social** scientists **have** for several years claimed that we are shifting to a Post-industrial society. This does not mean, however, that less and less hard products will be **produced**, substituted by soft products or services.

A **recent** study by **Gershuny**⁴³ is illuminating in this respect. While the level of **service** activities is increasing, this merely means that the hard products we

buy **have** a higher **content** of **service** activities 'in their added **value**. While industries are buying more and more industrial services the **reverse** seems to be the case for personal services. If **one** looks at the way that personal services are performed **one** can **detect** a trend of increasing complexity and reduced efficiency (**school**, **health**, **social** services). Gershuny suggests that new hard products are emerging that, together with the availability of an increased amount of free time (reduced working hours), heighten the possibility of substituting personal services that were previously bought with do-it-yourself work. Examples range from **the substitution** of barber services with the safety razor, to **magnetic** tape substituting for University **lessons** (eg the case of the UK Open University), to using family computer terminals and special detectors for **medical** check-ups as substitutes for doctor's visits (at least for a **first** screening and for minor illnesses).

Enough has been said in the past few years on the effects of the **informatics** revolution. It is suggested here that the revolutionary effects of information technology, which are still to be seen, will come about because of the increased complexity of our society's 'open system', due to the very **success** of the **latest** wave of development (an affluent society, increased **social** security and **social** equality, worldwide person-to-person communications and interactions). This increased complexity is **displaying—firstly** in the **social** services—a *decrease* in efficiency. No matter how popular a conservative **political** approach might become (dreaming of going **back** to the 'good old days' when society was less **affluent** and less **complicated**), the *process* whereby **there** is progress in the open system will derive from using at a 'higher level of **intelligence**' the information technology available, from simplifying the use of complex knowledge (by packaging it in a way different from today), and from recuperating a greater **role** for individuals, possibly beginning in the nature of the **service** products themselves.

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