The Darwinian Evolution of Machines?: An Enquiry.

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Introduction

There is a program or project, recognizable in the work of some sociologists and philosophers, known as "evolutionary epistemology".[1] Amongst other objectives, this program seeks to extend a theory of biological evolution to include social and cultural traits. The idea of evolution is one of those grand unifying hypotheses which seems to be applicable in so many realms that it has been described by the philosopher Daniel Dennett as "a universal solvent"

It is in this context that my topic may have some philosophical interest. By examining a very small field of culture, with which I happen to be rather familiar, perhaps I can throw a glimmer of light on the larger question. The nature of my enquiry is this: in what sense is it true that machines “evolve”, and what evolutionary model best fits this process?

My success will depend on the generality with which it is feasible to formulate an evolutionary theory. If I were to stick too closely to the Neo-Darwinian synthesis that incorporates the Mendelian theory of particulate inheritance and the DNA mechanism, it would establish too rigid a model of evolution to provide a useful analogue outside the limited field of biology. Bearing in mind the fact that Darwin himself had little idea of how the mechanism of inheritance was effected, a model closer to his original formulation (in which the mechanism of inheritance is treated as a “black box”)[2] is more appropriate than a Neo-Darwinian one. In contemporary language perhaps I could state it as follows: It is the idea that in all forms of evolutionary change there is a pattern with common elements: the generation of variety, the existence of replicators, and the selection of entities for preferential replication within a given environment. A necessary corollary is the phenomenon of extinction or obsolescence. When I say "all forms of evolutionary change" I include living creatures, ideas and technological artefacts.

But before saying another word I feel bound to read this warning from Stephen J. Gould:[3] " I am convinced that comparisons between biological evolution and human cultural or technological change have done vastly more harm than good - and examples abound of this most common of intellectual traps....Biological evolution is powered by Natural Selection, cultural evolution by a different set of principles that I understand but dimly."

Darwin's own summary was simply this: "a theory of descent with modifications through variation and natural selection." It was his opinion that a naturalist considering the origin of species and taking account of affinities, of embryological development, geographical distribution and fossil succession would have to conclude that they were the lineal descendants of some other and generally extinct species rather than being independently created. But how this had come about presented a much tougher problem. It simply wasn't good enough to invoke a response to climate, food etc. Darwin devoted his life to gaining a clear insight into "the means of modification and co-adaptation". He started by studying the breeding of domestic animals, which is very significant because animal breeding and its successor, genetic engineering, bridge the gap between biology and technology. Darwin went on to apply Malthus's doctrine of the exponential growth of populations and from it deduced the struggle for existence which caused "variations profitable to their possessors to be naturally selected." Further, he postulated that the selected variety would tend to propagate its new and modified form.

Darwin's theory was offered as a replacement of the theory of special creation in which he

had himself formerly believed. According to God's writings each species had been created independently and there was no connection between them. But to those seeking to undermine Darwin's dangerous idea, the rival theory of an impoverished French aristocrat named Jean-Baptiste-Pierre-Antoine de Monet de Lamarck provided useful ammunition and has been offered as a better analog than Darwinism for the evolution of machines. I shall therefore give a brief account of this theory based on his Zoological Philosophy published in 1809. His ideas, incidentally, were not entirely rejected by Darwin although they probably should have been.

Lamarck said that all species were connected through imperceptible differences in a single lineage, with just a few branches, up which they moved under the impulse to increase their complexity. Faced with certain difficulties in bringing his great scheme of zoological classification into harmony on this basis, which, incidentally called for evolving the duck-billed Platypus from the Penguin, Lamarck introduced the supplementary hypothesis that the response of the living animal to its environment, calling for the greater use or disuse of certain organs, exerted a positive feedback upon the hereditary apparatus (of whose nature of course he had no inkling) so that the children of that individual were better endowed than their parents to tackle the same problems. This hypothesis is commonly referred to as "the inheritance of acquired characteristics" and is equated by the ignorant with Lamarck's total theory.

I left God out of this argument because I think she has an unfair advantage, being omniscient and infallible and all that sort of thing, but I have to say that the model of her activity is, in some respects, rather close to the model we deduce from the history of technology because it involves the injection of purpose and intelligence into the evolutionary process. Darwin's model contributes the essential elements of variety-generation, replication, and selection, to which I shall devote most of my remarks, but it excludes intelligent intervention. Lamarck contributes the concept of feedback -- though of course he did not frame it in those terms -- but he thought that it applied to the biosphere, which it certainly does not, whereas I do think it applies to the technosphere.

The machines of my title are simply a figure of speech - in this case a synecdoche - standing for technology. I chose it because I had been reading Samuel Butler's “Book of the Machine” in his novel “Erewhon” and through this stumbled upon an earlier essay, dated 1863, entitled “Darwin Among the Machines” and another title "The Mechanical Creation." published later in the same year. In these writings Butler anticipated by some four years observations made by Karl Marx on the evolution of machines. In Marx’s view a key event in the evolution of machines was the invention of the slide rest which took the tool out of the workman's hand and thus partly out of his control. Further evolution gave rise to various degrees of automation leading to the next big event was when machines were able to build machines. The story continued after Marx's time with the acquisition of sensors by the working parts so that the state of the work could be signalled back to the machine in a feedback loop. This is the field of cybernetics of which Butler had strong intimations. He thus anticipated by over a century the findings of Professor Zuboff author of "The Age of the Smart Machine." This was precisely what Butler was warning his fellow citizens about. Machines were getting smarter and we would end up being their servants. We had better smash them while there was time. Butler later wrote four books on evolution based on an untenable theory of inheritance but these can safely be ignored.

Butler gave several examples of the way in which the evolution of machines was like the evolution of animals; some of these were illuminating, some were wrong. For instance, he was aware of what is sometimes called Cope's Rule, that members of a lineage tend to get larger. The

lineage of horses from the Eocene to the present is a classic example. Butler thought this rule could also be applied to machines. Well, one only has to look at the history of the computer and many other electronic artefacts for disconfirmation of that generality.

We have now available some well documented lineages of artefacts that provide striking analogies with lineages of fossils such as one may see in the display cabinets of the Department of Geology. The evolution of the felling axe in North America shows a gradual enlargement of the poll which gives impetus and balance to the blade. This has been interpreted as a response to the challenge of the virgin forest presented to a tool developed to deal only with the secondary growth of European timber. This sort of evidence further supports the biological analogy.

Butler's dystopia is by no means the only apocalyptic vision that can be derived from the biological analogy. Many writers, including reputable biologists, have offered the alternative vision of cyborgs or of a cybersymbiosis[4], the evolution of parts of human beings in future composite life forms with machines. But it is time to get back to my enquiry.

Extended man

We can pictorially display the lineages of all living things as a branching tree whose height is simply a measure of geologic time with no explicit judgement of value. Near the top of one of the main trunks we find three branches of chimpanzees One of them is called the hominids. And a twig branching off from part of the branch labelled Homo sapiens is labelled var. faber the toolmaker, though I think we could make a case for calling it var. ludens, the playful one. This playful tool maker has extended the human body with all sorts of exosomatic appendages (outside the soma). I believe we owe the term to Peter Medawar but the metaphor "extensions of man" has a considerable prior and later history. Samuel Butler used in 1863. George Garrett picked it up in the nineteen twenties; Freud in the thirties referred to auxiliary organs and to man as a prosthetic god; and of course our own Marshall McLuhan put it on the map in the subtitle of his popular work "Understanding Media: The Extensions of Man." Thus the telescope and the microscope are extensions of the eyes, the pressure cooker an extension of the stomach, the wheel an extension of the foot, clothing an extension of the skin, the computer an extension of the brain and so forth.

The point I am making here is that there is in a very real sense a continuity in the tree of life between two kinds of man, with and without artificial extensions. This is something which would be deduced from the fossil record by an alien visitor If we view Extended Man, the species of Homo that is equipped with technology, as a special branch of the tree of life, then, prima facie, I believe that he should be studied with the same conceptual tools as are used in the study of the rest of the tree. This stance gives us grounds for applying evolutionary epistemology to the study of machines. Or, to put it another way, to use the model of organic evolution to further our understanding of technology, either as a useful analogy or merely as a metaphor. Samuel Butler had already spoken of "mechanical life" in the essay I mentioned earlier. A rather more sophisticated formulation of this idea is that biological evolution and cultural evolution are both operating in the same "design space" and must therefore have similar strategies.

The Nature-Machine Analogy

The comparative development of Nature and machines was used by earlier philosophers in their attempt to prove the existence of god (the so called “argument from design”). Given that the world of artifice was the product of intelligence, they were concerned to show that the world of Nature was so similar in its unfolding that a divine intelligence must have created it. They therefore used machines as analogs for understanding nature in contrast to Butler who used Nature as an analog for understanding machines. Hume's “Dialogues” featured Cleanthes defending the Argument from Design with the metaphor of machine being applied to the whole of the Natural world.

"Look around the world. Contemplate the whole and every part of it. You will find it to be nothing but one great machine, subdivided into an infinite number of less machines, which again admit of subdivisions to a degree beyond what human senses and faculties can trace and explain. All these various machines and even their minute parts are adjusted to each other with an accuracy which ravishes into admiration all men who have ever contemplated them. The curious adapting of means to ends, throughout all nature, resembles exactly, though it much exceeds, the production of human contrivance - of human design, thought wisdom and intelligence. Since therefore the effects resemble each other, we are led to infer, by all the rules of analogy, that the causes also resemble..." Butler's story made the same appeal to analogy with the roles of model and analog reversed. Both Butler and Cleanthes were on shaky ground in their appeal to the rules of analogy - and that, I think, lends force to Stephen Gould's admonition.

Hume, speaking through Philo, tries to demolish Cleanthes' arguments and looks as if he is going to win; but he hasn't the intestinal fortitude to go through with it because of the obvious challenge to Christian dogma, and so he cops out. I hope that one by-product of this talk will be to give Philo some more ammunition for his next round.

The tradition of using machinery and engineering to explain the workings of nature continues to this day, and has been applied to the problem of organic evolution by François Jacob in his essay on evolutionary tinkering. He was concerned to show the very opposite to Cleanthes: that the evolution of organisms proceeds, not according to design, but in a manner which in machinery we should call tinkering (bricolage). Unfortunately, I think Jacob overstated his case for the contrast between the two realms when he said that "In contrast to the engineer, evolution does not produce innovations from scratch." In fact, neither Nature nor the engineer produce innovations from scratch and this is one of the striking similarities between the two systems. For both Lamarck and Darwin the continuity of lineage is fundamental to their theory and the same continuity can be demonstrated for machines. It has been particularly well documented in books by George Basalla (1988) and Henry Petroski. Even when an apparent change of horses is made in mid-stream, say from the propeller-driven aeroplane to the jet-propelled, or from the thermionic valve to the transistor, the new technology is the product of a historical lineage. And if, as is so often the case, a great leap forward in technology happens through the application to a new purpose of a device developed for something quite different, the similarity to Nature is further reinforced. In biology this phenomenon has been called "exaptation". There is, for example a species of Heron that has exapted a wing into an occasional sun visor the better to spot its fishy prey beneath the reflecting waters of a pond. George Dyson, in his book named after Butler's "Darwin Among the Machines" suggests that feathers, the great biological innovation that led to the conquest of the air, had an original function quite unconnected with flight. My archetypal

example from technology is the punched card, developed for producing music in automata, transferred to the Jacquard loom for controlling patterns in weaving and ending up as an input device for computers.

While I am still dealing with Jacob, let me quote something of his that I agree with entirely because it will enter into the next part of my story:
"Complex objects, whether living or not, are produced by evolutionary processes in which two kinds of factors are involved: the constraints that, at every level, specify the rules of the game and define what is possible with those systems; and the historical circumstances that determine the actual course of events and control the actual interaction between the systems". I can relate this immediately to my studies of innovation.

The innovation model

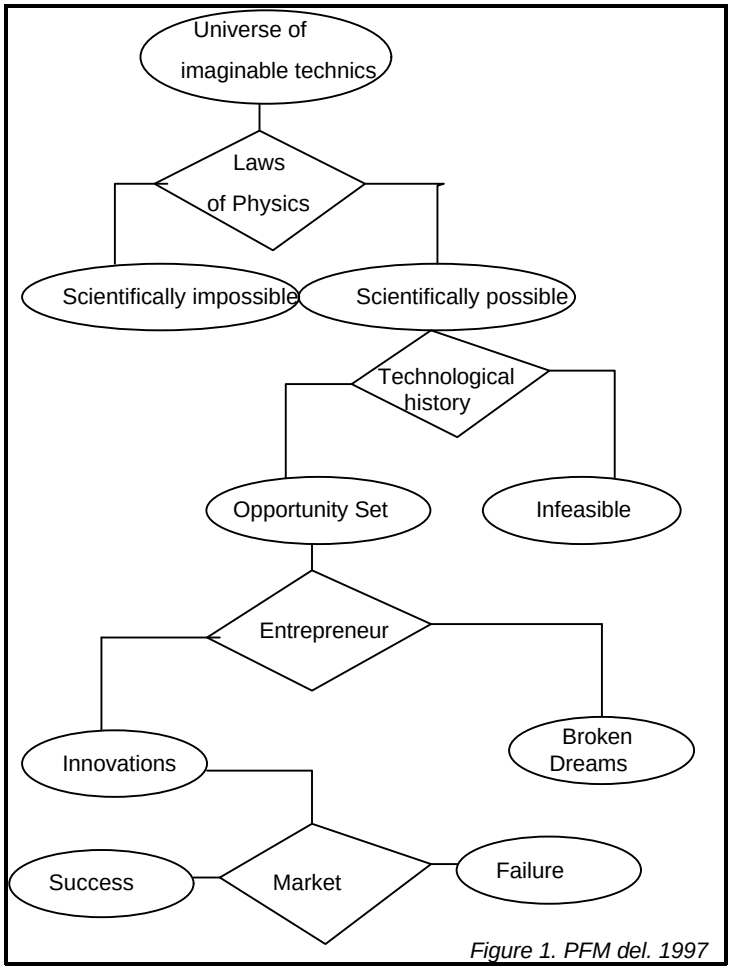


Figure 1. PFM del. 1997

Some years ago, for teaching purposes, I designed a graphical model of the process that leads from invention to innovation - generally considered to be the engine of growth in a modern capitalist economy and thus of prime importance to students of technology in society, as well as to economists and management theorists. Having completed it, I was very struck by the similarity between my model and what I understood to be the process of evolution through natural selection that had been described by Darwin. I recognized in the model all the fundamental elements of evolution by selection. The first step, which we call invention, comprised the generation of variety under a set of constraints set by our state of knowledge and the history of prior development or "state of the art", in short

"constraints and history" as Jacob insisted.

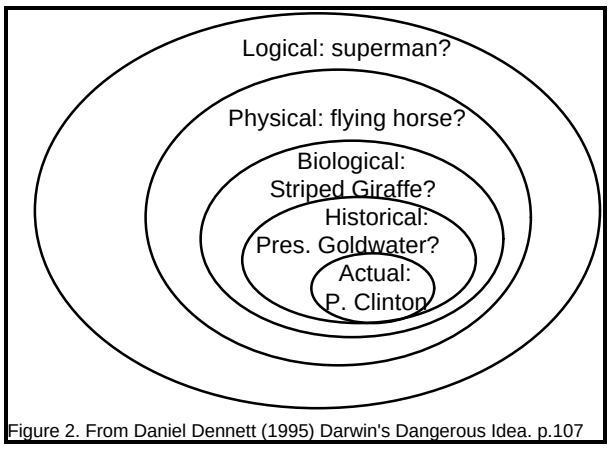


Figure 2. From Daniel Dennett (1995) Darwin's Dangerous Idea. p.107

Jacob's book, from which I recited a quotation a few minutes ago is entitled "The possible and the actual" and it is, of course, of great interest to the technologist as to the biologist to consider what paths are possible and why, out of all these, only a few are selected for actual innovations.

Compare the upper part of my diagram with the diagram by Dennett illustrating the grades of possibility for the existence of any kind of organism. The two diagrams share a logical structure and, if the word "technological" were substituted for "biological", Dennett's diagram could be applied to innovation theory without further change.

My diagram depicts a logical linear model of the process of innovation but it should not be assumed that this corresponds to the actual sequence of events in time; these involve various feedback loops.

We start with the concept of the universe of all imaginable techniques and immediately divide these into fantasy and potentiality on the basis of our current understanding of the laws of physics. Inventors work to generate variety at this level, "pushing the envelope" which at any given time demarcates the possible from the surrounding realm of the imagination.

Technological history determines the next level of filtration; part of this comprises the state of the art which has been arrived at over time in the many disciplines contributing to the invention, for instance the current physical limits on the dimensions of microprocessors. But the more interesting phenomenon, which is closely parallel in biological and technological evolution, is the quasi-deterministic influence of past evolutionary steps.

There are many expressions which have been used to describe this. I like the term QWERTY phenomenon which refers to the leftmost six letters on the upper row of a typewriter keyboard. This arrangement of letters was arrived at in the earliest days of the typewriter, for reasons that do not apply to an electric keyboard. But such a huge investment in skill, in training, in emotion, has been made in this keyboard that there has been repeated failure in the attempts to rationalize it and to introduce an arrangement of letters proven to produce more output with less strain. The QWERTY keyboard is simply emblematic of a widespread phenomenon which is less colloquially referred to as "lock-in", embedding, or as entrenched technologies. The reason we have VHS rather than Beta-max video recorders is another story of lock-in which has been

documented by the economist W. Brian Arthur.

The same phenomenon is found in biology; the bones of the ear have to be fashioned from some left over stuff from the reptilian jaw. The fact that we have five digits on our hands and feet is presumably a QWERTY phenomenon.[5] Another example sometimes cited is the recurrent laryngeal nerve which takes an apparently bizarre detour behind the aorta even in the giraffe.(Dawkins: 1986, 38).

I refer to the inventions that pass the filters of technical constraint and development history as "the opportunity set". This is offered to the entrepreneur who makes the first critical selection by conjuring up a virtual market in his or her imagination. "Mammals and birds and reptiles and fish all exhibit the capacity to use information from their environment to presort their behavioural options before striking out"[6] so this activity is as much biological as technological. The entrepreneur then sets in motion the process of replication and submits the innovation to the test of reality. This usually involves a further virtual step in which facsimiles of the innovation in the forms of illustrations and text are replicated and distributed. Occasionally the actual artefacts are replicated in quantity and thrown into the environment in a process very like that of nature's. For example, the mass distribution of America On Line Diskettes through the mail.

The final selection of innovations takes place in the Market. Either they survive or perish. It is here that Herbert Spencer's phrase "the survival of the fittest" truly applies -although it is of course a tautology.

How does this model of technological innovation compare with the origin of species by natural selection.?

There is first of all, in both realms, a process for the generation of variety. In the organic realm we have mutations of genes, jumping genes and the general musical chairs that takes place in biparental reproduction -- and that is probably the most important. In the realm of technology we have the constant push to invent, which may itself be rooted in our biology as Homo ludens.

The role of constraints and of history that Francois Jacob deemed central to the evolution of complex objects seems to me to apply equally to the realm of nature and the realm of artefact, to the biosphere and technosphere. But at this point in my enquiry I ran into the problem of "back-tracking" -- or what the French call:

Reculer pour mieux sauter

This French expression means to draw back in order to jump further. This is quite characteristic of technological development and extremely rare in biological development. Let me give some examples from technological history. The steam engine is a favourite and much studied case. It seems clear that the early models of the Cornish engines did not match, let alone exceed, the mechanical efficiency of the best Watt engines, and the early steam turbines introduced around 1915 were greatly inferior to the series of compound, triple expansion and uniflow engines of the previous fifty years. Nevertheless, in both cases, the new technology went on to surpass the old by a handsome margin. Technological evolution, being a product of mind, is amenable to foresight. Biological evolution, being mindless, is not.

One way to get a handle on the problem is by using the metaphor of a fitness landscape, first described by the evolutionary biologist Sewall Wright in 1932. In his original description he showed a simple contour map with a series of elevations and depressions. The contour lines were intended to represent the scale of adaptive value of a universe of possible gene combinations under a given set of conditions.

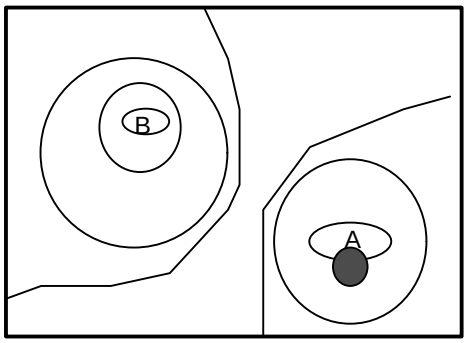


Figure 3 A "Fitness Landscape": Problem
Given species A to evolve a species .
occupying Hill B.

Calculations show that there can be a very large number of harmonious combinations of genes that will have adaptive value and these can be depicted by separate peaks. An interbreeding species whose actual gene combinations locate it on the slope of one of these peaks will move up, under the pressure of natural selection, until it reaches the top. The problem for Wright was presented by a case in which the adaptive value of the conquered peak was low compared to another peak - how to get the species up the other peak? In other words, could the genetic combinations be induced to "reculer pour mieux sauter" -- to make the necessary descent into the adaptive valley? When hydrogen was lost from the atmosphere of Earth, oxygen began to increase and proved fatal to most organisms but the aerobic bacteria developed and proved more successful than ever. How did this come about?. Wright attempted to show that species could move downhill by means of non-selective processes; and even strict Neo-Darwinists of the modern school while reiterating the hill-climbing law of "never down, up if you can" also invoke genetic drift, a selection-free phenomenon which relies upon the rate of mutation to move the population downhill; yet others, also following Wright, invoke a change in the environment and thus in the topography of the fitness landscape which, as it were, allows an evolutionary escape route. Neither school could admit of a strategy of selective downhill movement for the purpose of climbing a higher hill. But, of course, that is just what we expect of technology produced by a firm that can survive a short-term trip through the valley, or bluff or bully its way out of it. The early versions of Windows software seem to me to fit that description.

A special case of back-tracking in technology is called reverse engineering. This is normally applied by countries or firms without R &D to work back from a finished artefact by analyzing the functionality of every part and then re-engineering it. It would be hard to find a biological analogue for so cerebral a project.

Let me now add another piece of evidence for similarity. It is one spotted by Samuel Butler himself. It goes by the technical name of

Skeuomorphs

Both biologic and technic objects develop skeuomorphs, the functionless remnants of homologous active organs in their ancestors. Darwin referred to these as "rudimentary" although I think they are more properly called "vestigial" organs and they are strictly analogous to the skeuomorphs of artefacts. The most obvious example of a skeuomorph is the marble ornament on a Greek temple that represents the end of the joists that were part of earlier wooden constructions.

Samuel Butler pointed to the knob on his pipe which he supposed to represent a former

base for resting the pipe on the table. The little bow inside the headband of a man's hat represents the bow that tied his queue or pigtail. Automobile design is rife with skeuomorphs as features necessary for steel fabrication are reproduced in plastic. Snakes' feet and our appendix, and for that matter men's ugly toe-nails[7], are amongst the skeuomorphs of the biosphere. Thus truly analogous features of this kind mark the evolution of both living creatures and machines.
I have demonstrated a process of variety-generation in technology which corresponds to the process of variety generation in biology. I hope I have shown the close similarity between the role of physical constraints and of developmental history in both realms. In both realms selection takes place from an overabundance of variety; the measure of success in each case being survival and replication, in the environment and marketplace respectively.

A vital part of the puzzle is still missing -- the nature of inheritance in the two realms--the means by which descent with modification takes place.

Replicators

Richard Dawkins considered it a fundamental principle that "all life evolves by the differential survival of replicating entities." In the biosphere the genes are the replicators. They catalyze both their own replication and the production of the phenotype which is to carry them forward in the world. In technical terms they are both autocatalytic and heterocatalytic. (They appeared when Darwin's "black box" was opened.)[8] Dawkins introduced the term memes to denote the replicators in cultural evolution and any attempt to push the machine-organism analogy further will involve an examination of the role played by memes in the replication of artefacts.

Memes

Dawkins first put forward the idea of memes in "The Selfish Gene" in 1978 in which the last chapter was devoted to "Memes, the new replicators". But he clarified his ideas in a book called The Extended Phenotype: The Long Reach of the Gene. of which he said in 1989 "It doesn't matter if you never read anything else of mine, please at least, read this." A gene is clearly a physical object composed of a double strand of DNA but what is the physical nature of a meme? (It seems to me that its present status is very like that of Darwin's black box before the work of Mendel and the molecular biologists.)[9] In Dawkins' glossary it is described as a unit of cultural ineritance, hypothesized as analogous to the particulate gene, and as naturally selected by virtue of its 'phenotypic' consequences on its own survival and replication in the cultural environment." The text provides added clarification. "A meme should be regarded as a unit of information residing in a brain. It has a definite structure, realized in whatever physical medium the brain uses for storing information. If the brain stores information in a pattern of synaptic connections, a meme should in principle be visible under a microscope...." However, Dennett[10] concludes that: "..the meme is primarily a semantic classification, not a syntactic classification that could be observed in brain languageö or natural language." In other words the meme is identified with meaning, not with structure.

Dawkins then describes the phenotypic effects of a meme, analogous to the phenotypic effects of a gene. He says the phenotype "may be in the form of words, music, visual images, styles of clothes ...skills etc." It is the phenotypic effects of memes that are exposed to competition and thus selected for differential replication.

Daniel Hills illustrated this idea with songs[11] but in his description I have substituted the phrase "computer programs" for "songs": "Computer programs are replicated, die out, or are combined with other computer programs. They may therefore be considered a form of life. They

survived, bred, competed with one another and evolved according to their own criterion of fitness." One could say the same of other artefacts.

DNA makes copies of itself using intracellular material in the form of replicases. The meme copies itself using "the apparatus of inter individual communication and imitation." The social climate in which this happens corresponds to the cellular climate in which the gene replicates.

Dawkins is at pains to demonstrate that the organism is not the replicator. The gene and the meme are replicators and the organism is a communal vehicle for both of them. However, organisms are not the only vehicles; there is a whole hierarchy of them. "A vehicle is an entity in which replicators (genes and memes) travel about, an entity whose attributes are affected by the replicators inside it, an entity which may be seen as a compound tool of replication or propagation." Books are the archetypal meme vehicle but "Tools and buildings and other inventions are also meme vehicles."[12] Extending this idea to my theme this evening, I conclude that a machine not only performs a technological function but also carries information as a meme vehicle: it carries the idea of the machine.

When a remarkable piece of intricate mechanism was discovered in an ancient Greek shipwreck, it was possible to deduce from it the set of astronomical ideas that led to its construction. It was thus a meme vehicle but since the ideas were obsolete there was no incentive to reproduce either the meme or the vehicle.

Memes, like genes, are potentially immortal, but like genes they depend on the existence of a continuous chain of physical vehicles, persisting in the face of the second law of thermodynamics.

Can we arrive at a theory of evolution by natural selection which is sufficiently abstract to embrace both genes and memes? In other words such that one cannot tell whether a biological or a technological situation is being described. A sort of Turing test.

The following outline by Dennett's seems to me to fit the bill. He claims that it is clear that evolution occurs whenever the following conditions exist.

1. Variation: there is a continuing abundance of different elements.
2. Heredity or replication: the elements have the capacity to create or catalyze copies or replicas of themselves.
3. Differential fitness The number of copies of an element that are created in a given times varies, depending on interactions between the features of the element and features of the environment in which it persists.[9]

In conclusion I shall attempt to adjudicate between those who see a Darwinian process in the evolution of machines and those who claim that, on the contrary, it fits a Lamarckian model.

Darwin versus Lamarck

As I mentioned in my introductory remarks, the :Lamarckian idea of evolution is totally different to the Darwinian. And although neither Darwin nor Lamarck had a clear idea of the mechanism of inheritance, their theories had contrary implications for the relation between the germ-plasm and the somatic body, between the genome and the phenome. I have found it helpful to the clarification of my own thoughts to put this in cybernetic terms, using the metaphor of a feedback mechanism.(Figure 5)

In the Neo-Darwinian model, information feedback from the environment affects the somatic body but the genome is insulated from feedback. In the Lamarckian model, the system would only work if feedback from the environment transmitted an effective message to the "genome" via its effects on the phenotype. This will work if there is a meme in the box but not if there is DNA in the box.

Applying the feedback model to the evolution of machines, it is clear that feedback from the environment (which in this case is the Market) does convey an effective message to the analog of the genome, which in this case is the meme complex. In this respect, the evolution of machines is Lamarckian.

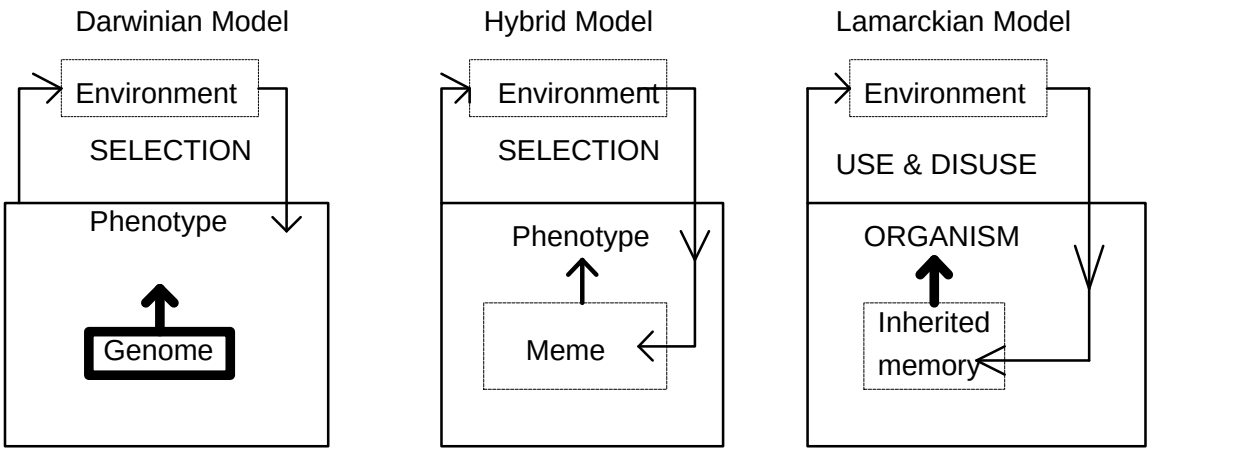
In other respects, notably in the metaphor of competition and selection, it is Darwinian. Hence I have tried to represent it with a hybrid in Figure 5. The evolution of machines also fits the Darwinian metaphor of the branching tree. Lamarck's tree had a few branches, very grudgingly included through the failure of the main theory to accommodate all his observations into a single continuous line of descent.

A major difference has been claimed, particularly by Alfred L. Kroeber,[13] between the tree of life and the tree of cultural artefacts in that the former is like a living tree, in which branches separate but never rejoin, whereas the latter is anastomosing; that is, branches not only diverge, they come together or converge again. The criss-cross of lineages is in fact one of the most powerful sources of variety and novelty in the mechanical world -- functionally taking the place of sex, or more technically, biparentalism, in the biosphere. Consider the convergence of the telephone and photocopying machine to make a fax machine for example; or the convergence of carriages, water pumps, scent sprays, and electric pistols to make an automobile. However, I believe that Kroeber exaggerated the difference between the biosphere and technosphere in this respect.. Many hybrids are fertile, despite popular belief to the contrary - a fact Butler brought to the attention of the readers of the Christchurch Press in 1863. Moreover, symbiosis, as in the well-known conjunction of plant and fungal tissue to form a Lichen is probably much more important in the biosphere than we imagine. Lyn Margulis's speculation on the bacterial origin of the organelles in the cell, greeted with scorn when first put forward, has since been widely accepted. She and Donna Sagan go much further in their claims in the book *Microcosm*, which I recommend. This surely strengthens the Darwinian analogy.
(For that matter, two anatomosing poplar trees, known as The Medicine Tree, stood for many years in a sacred grove at High River, Alberta, where they were the objects of veneration by people of the First Nations. So even the tree metaphor fails.)

Finally, if we compare extinction to obsolescence, the verdict must be ambivalent. When a living organism becomes extinct it is extinct for good. I hear you murmur - what about Jurassic Park? The science behind Jurassic Park is fundamentally flawed because the mere preservation of genes does not allow the replication of the organism of which they once formed a part. The developmental history of organisms takes place in a cellular environment which is also unique to the organism. The DNA can catalyze its own replication in a petri dish but cannot bring about the development of a phenotype without the cooperation of the other elements of the egg. If a fertilized egg is preserved, the species can hardly be said to be extinct. On the other hand, a technical device, once obsolete, is likewise most unlikely to be revived because the environmental conditions suitable for its selection have vanished. But in this case it is not impossible. As long as the meme survives in archival form the phenotype can be resurrected. This then is closer to the Lamarckian model than the Darwinian, for Lamarck believed that no species had ever died out; if there were missing links in his lineage it was because they had retreated to places inaccessible to human exploration such as the depths of the oceans.

My conclusion is that the mechanism of evolution found in the world of machines is neither wholly Darwinian nor wholly Lamarckian but partakes of some characteristics of both. And indeed it must also call upon a "deus ex machina" to provide the purposeful and directed trajectory of

technological change; for the almost instantaneous introjection of design into technology in contrast to the painfully slow emergence or poiesis of design in nature. That deus is of course itself the product of biological evolution, the process which has turned us into what Sigmund Freud called a "prosthetic god".



No information from the phenotype enters genome.

Information from the environment enters the meme via the phenotype The meme is expressed in its "phenotype"

The organism is altered by interaction with the environment and a memory of this interaction is inherited.

Figure 5 PFM *del.* 1997

1. David L. Hull, p.273

2.Parenthetic statement added.

3.1991

4.Margulis & Sagan

5. Dennett, 131

6.Dennett, p. 376

7.This is a reference to a currently ubiquitous advertisement.

8.Parenthetic statement added.

9.Parenthetic statement added.

10.Dennett, p.353

11.Daedalus Winter 1988 quoted in George Dyson, 1997 p.223.

12.Dennett

13.Kroeber, A.L. (1948) *Anthropology*. Harcourt Brace Jovanovich.