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# BIOTECHNOLOGY AND INFORMATION TECHNOLOGY AND THE COMING MERGER OF SCIENCE, TECHNOLOGY AND CULTURE

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Biotechnology and information technology are the two generic technologies which are poised to have a major impact in the coming decades. Students of generic technologies have pointed out that their impact would be much greater than the earlier generic technologies associated with the Industrial Revolution and its aftermath, including such technologies as those asssociated with steam, electricity, chemicals and oil[1]. But the two technologies replace and/or intimately affect respectively life processes and cultural processes, so that their impacts could be much deeper, possibly as significant as the technological turning points of the palaeolithic and neolithic eras.

Yet, the two technologies deal with two streams of information. In the first biological information, in the form of genes and strands of DNA and, in the second, in the form of "artefactual" information primarily as digital based data and software. In dealing with these two information streams, another information stream, namely that of human culture in the particular form of scientific information, becomes a principal actor. This process results as this paper will attempt to show, in the literal merger of some aspects of the three streams. In addition, aesthetics and the fine arts impinge on the two non-human streams. This arises firstly from the aesthetic aspects that underlie many key scientific works. Secondly and in a more pervasive manner, there is an intrusion of aesthetic criteria in some aspects of biotechnology as well as the encroachment of information technology in many arts, often resulting in multi-directional traffic.

This paper will first demonstrate the existence of the streams – "lineages"– of information, then describe their processes of merging. And in a final section, illustrate the consequences of the merging of the streams.

**The Biological Lineage and Biotechnology**

The biological lineage is the tree-like structure of species and their evolution as demonstrated by Darwin and Wallace and subsequently fleshed in through the work associated with Mendel, the New Synthesis and, most importantly, the work of molecular biologists of the last forty years. The lineage consists of strands of DNA which stretches back nearly four billion years. Since that time, the lineage has been bifurcating in response to changes in the environment giving rise to the myriad life forms that we have today. There is also a "phylogenetic ascendancy" in the process, the more complex genetic information occurring later because there had been a greater time for the evolutionary process to occur.[2] And, sometimes, the evolutionary changes may not be smooth but would display characteristics of punctuated equilibrium.[3]

There are two other important characteristics of biological evolutionary systems which recent commentators have pointed out. The first is that the system is in a process of self-organization and self-construction – termed "autopeosis".[4] The second is that the encoded information in genes is a window to the external environment, the external world. Some biologists have therefore seen the encoded information as ecological perspectives or "theories" that change with the environment. Such a Gestalt is encoded in the genome and is considered to have its own "subjectivity" on the world,[5] its own "world view" to the outside world. These have been called "egocentricities" by Morin;[6] and, as these lineages course through time they change.

This biological lineage is now about to be profoundly and intimately intervened-with by direct human actions through biotechnology. Biotechnology would potentially allow the intermixing of the entire genetic heritage of the last 4,000 years. It would allow genetic material to cross species boundaries including those across bacteria, plants and animals. It would potentially allow for an extreme plasticity in the transfer of genetic characteristics with, say, the realization of many transgenic plants and animals.

**The Cultural Lineage**

Genetic information is not the only information lineage one sees in biological systems. With the passage of time in evolution, a more adaptive information system in the form of culture emerged. Cultural transmission of information occurs in some low animals but it is in primates and especially in humans that it takes a dramatic form. Human culture provides for a stream of information, a lineage, that is handed down from generation to generation. Thus "a given culture trait can be fully understood only if seen as the end point of specific sequences of events reacting back into the remote past".[7]

Cultural information speciates and bifurcates in a parallel manner to the genetic lineage as it changes its internal information stores in response to changes in the environment. A tree-like structure like that in the traditional evolutionary tree of biology results; in this case, it is the tree of knowledge.

The cultural information associated with formal information, namely science, has been studied in considerable detail over the last ten years by sociologists, especially by the school associated with the "social construction of science". They have demonstrated how scientific information is constructed socially by interactions in a social environment. The studies show the construction of science through social influences, at the level of the laboratory, the peer review of a journal article,[8] international competition, national politics that influence such mundane factors as funding for a particular line of research,[9] and even the influence of a particular *zeitgeist*. The result is a tree of scientific knowledge that grows and bifurcates responding to a variety of social forces. The bifurcations result in disciplines and subdisciplines as they develop their own rules and own sets of information that are incompatible with others and impervious to them.

The properties of the cultural lineage – which have parallels with the biological one – include speciation (to, in this case, disciplines and subdisciplines), the persistence of past memory, self-construction (social construction by interactions between members), subjectivities ("egocentricities") associated with a lineage ( in the manner of a particular discipline's "views" on how to deal with the data on the world that is given to it, a phenomenon parallel to other social subjectivities in larger social lineages and equivalent to say class or group consciousness), and sudden changes in cognition as in paradigmatic changes.[10]

The lineage develops new cultural information from its past store of information as well as adding new stores. Sometimes a set of information or rules developed in one discipline is transferred to another. Sometimes the transfer is done indirectly through metaphors. It has been noted that much of the knowledge of the world is forged through metaphors, the metaphor thus becoming "the pregnant mother"[11] to science and to all seminal thought.[12] It has also been pointed out that the formation of concepts using metaphors in scientific reasoning is largely a metaphoric one. Metaphors generally transfer semantic characteristics from one field to another.[13] Metaphors help by "juxtaposing the familiar with the unfamiliar while exposing similarities and differences between the literal use of the borrowing and a new area".[14]

Some of this metaphoric transfer occurs from the humanities and the arts. The history of science is replete with such transfers especially at key turning points in a discipline. This importance of the aesthetic factor has been pointed out by Wechsler.[15] Twentieth-century figures influenced by the aesthetic include such giants as Bohr, Dirac, Einstein and Heisenberg.[16] A key 19th-century figure would be Darwin for whom the imagery of an irregular branching tree antedated and foresaw his theory of evolution.[17] At the beginnings of science, too, the aesthetic was influential as in the belief of the circle as the most beautiful figure in the development of Corpenicus' ideas.[18]

**The "Artefactual" – Machine – Information Lineage**

Information associated with machines, "artefactual" information is that involved with computers and information technology. And it is today expanding exponentially. The nature of the technology is such that prices drop and capacities double every two years or so in the technology's key component – microprocessor chips. The nature of the rapid growth is indicated by a comparison made in 1978, nearly fifteen years ago. It had been observed that[19] if the improvements in the micro-electronic technology had occurred in the aeronautics industry, an airplane would by 1978 be carrying half a million (500,000) passengers, at a speed of 20 million (20,000,000) miles per hour at an air ticket costing less than one penny.

Indicators of the rapid development of the lineage was the fact that already by 1985 there were in the U.S. alone more microprocessors, that is, computers on a chip, than there were people.[20] With this type of growth, combined with rapidly falling price per unit of computation in the technology, it is reasonable to expect that there would be by the year 2000 more computing devices in the world than there would be people, although they would be unevenly distributed. These devices would often be ubiquitously embedded in devices, as they are already in watches and many appliances and machinery.

The growth of the technology is also fuelled by socioeconomic factors that are driving some societies to have a preponderant information sector, most of that information being increasingly cycled through computers. In addition, there is the evidence of the more rapid growth of information exchange between machines as opposed to that occurring between humans or that between humans and machines as evidenced by data in the field of what has been termed C+C (Computers and Communications).[21]

Information in these artifacts is generally considered only to be transmitted horizontally, synchronously across time as it is exchanged within a machine or between machines at any given time. But the information is also transmitted down vertically, diachronously, as the machine information that is transmitted once is retained only to be transmitted again down a chain of machines. Through this process, a lineage that extends backwards and forwards through time is created. This lineage is now only a few decades old but is growing rapidly as computer use grows exponentially.

This lineage also interacts with its external world, its environment, through its input and output devices. The lineage is, at the moment, tightly controlled without much internal flexibility apart from that given by its human mentors, just like, say, insects are tightly controlled by their genetic programming. But new developments in AI techniques including those that use learning systems, genetic algorithms, and neural networks provide for the lineage to become more adaptive to the environment and so change its internal stores accordingly.

The lineage grows initially according to the disciplinary boundaries and classification criteria set by humans, but as the information stores within the lineage is increasingly exchanged and operated on by internally generated rules, especially those set by learning systems, these boundaries begin to change according to new internal criteria. And so, new boundaries emerge in a process analogous to the formation of species.

In those situations, where some of the adaptive technologies operate, it is not possible for the human programmer to know even in principle the responses of the artefact to signals from the environment. They can now change their internal information states in non-trivial ways to changes in the environment. These changes can then be handed down, thus constituting an evolutionary lineage. It is also self-constructed through interactions with the environment. The lineage only samples its environment through the particular information fed to it. Hence its "view" on the external world is a particular view, a particular "subjectivity" that changes as the lineage changes its internal information system. It has been also observed that the lineage sometimes changes abruptly, apparently exhibiting evolutionary characteristics similar to punctuated equilibrium in biology.[22]

The field of artefactual information is growing exponentially for socioeconomic and technological reasons while the devices themselves are becoming increasingly adaptive. This gives rise to a rapidly growing lineage that is speciating and resulting in a tree-like structure as it interacts with its environment.

**Commonalities in the Three Lineages**

All three lineages have common characteristics. They include retention of a past memory, interaction with an environment, changes in the internal information stores, self-organization, speciation, sudden disjunctures and "subjectivities" associated with each lineage.

The lineages are also related to each other. They do not stand in isolation. The cultural lineage which reacts to the environment faster than the genetic came after the latter, because this faster reaction was more adaptive. There is thus a time sequence in the appearance of the three lineages. Similarly, the artefactual lineage has come into being because it reacts faster than the cultural one and hence can relate better to the environment in this sense. Changes in the genetic lineage occur over almost geological time, that in culture in, say, minutes and in the artefactual in fractions of a second.[23]

The three lineages are also nested one inside the other, the artefactual being the outer layer, the genetic – the inner one – and the cultural sandwiched between.[24] Because of this nestedness, there are limits given by an inner lineage to the flexibility of responses to the environment by an outer core. Thus, genetics limit what part of the visual or audio spectrum that a person can subjectively experience. Although, through instruments, one could transcend these limits in a cerebral sense, the experiential limits still exists. The inner core acts therefore almost like the hand in a glove, the glove being culture. Similarly, culture acts as the hand for the glove of artifacts. Culture gives the initial template as well as the intial limits for artefactual information, because it is humans who initially design and manufacture the system at both the hardware and software level. But, with the more autonomous newer technologies, the lineage increasingly becomes “freer”. Yet the cultural imprint still exists in the background, limiting the range of possible changes in information.

**Mergers**

Although the three lineages have existed up to the present in isolation, they are now becoming merged through developments in biotechnology and information technology.

Both biotechnology and information technologies constitute cultural acts. As cultural acts, they are influenced by the general social forces that influence science and technology. These include forces at the level of the scientist’s peer group, at the level of the market and at the level of geopolitical forces. But when a scientist or technologist does a biotechnological process, for example, splicing in a gene, he is expressing cultural information. This cultural information includes how the genome is strung together, which genes are active and which are “junk”, which combination of base pairs constitutes a particular gene and which gene codes for which protein. Equally relevant is the cultural information which decides which phenotypal characteristic is important say for the market or for the culture’s esthetics and which gene expresses this characteristic. This cultural information now directs the biological process in addition to the ones given by nature. It thus constitutes another set of information which is merged with the genetic information given by evolution and which now decides what biological act is to take place.

Biologists distinguish between two sets of genes: structural genes which code for a particular characteristic, and regulatory genes which state when the structural genes should come into play and when they should stop. The new cultural information acts as a set of higher information instructions superimposed on the regulatory ones.

And, once the culture, influenced genes are rearranged, they begin to constitute new lineages. They can now shuffle genes among themselves without human intervention and so could develop independently, eventually leading up even to new species.

In a similar manner, as with genetic information, cultural information also gets embedded in artfeactual information. Computers are also expressions of culture both at the hardware and software level. Just as in biological systems, there are a hierarchy of levels in computer systems: the application software which translates an immediate cultural need, the machine code which carries information of a more general, less immediate level and the information coded in the hardware which is on a longer time frame and less flexible. Cultural information of how to build hardware, of how to do machine code, of what are software requirements, and of how to do a particular application, gets merged in the artefactual information.

This cultural information, however, is molded by social forces at the level of the practitioner, nation and wider socio-historical context. Human discussions, negotiations, conflicts, consensuses, market forces, military and civilian demands, geo-political tensions have all shaped this cultural stream of information.

But once this culture – embedded information is coded in the artefact and the latter is allowed a degree of autonomy as in the newer techniques that modify their core internal configurations through environmental interactions, the direct cultural information's influence increasingly becomes less immediate. Given sufficient time the artefactual lineage now develops autonomously.

Not only does cultural information influence and merge respectively with genetic and artefactual information, so also does genetic and artefactual information in turn influence culture. Thus the genetic system sets the subjective limits of sight, sound, touch, and brain, including, in the case of the latter, the differences due to gender. Biologically we experience a world different from that of say a bat,[25] and as accumulating evidence of gender differences in brain structure reveal, so do we from the other gender. Biology sets the framework through which we view the world. But the new biotechnology and genetically invasive medical procedures are, through new therapies and nutrients, changing this physical grid through which we acquire culture. The genetic information in the potential gene therapies thus adds itself as another information system to the cultural system by changing its biological grid, biology merging with culture.

In a parallel manner, artefactual information changes human behavior and hence cultural information. The person sitting in front of a video terminal either in office or factory is responding in behavioral terms to the computer's output. This output need not be restricted to the visual, it can come in any form: voice, graphic or, for that matter, even smell and touch. Newer input-output devices like virtual reality dramatically increases the intimate admixture of artefactual and cultural information. In that sense, computer information gets merged with cultural information in the artefact user's mind as he internalizes it and reacts to it. With increased maturity of artefactual information as its autonomous nature increases, these interactions between culture and artefact would tend to decline relatively, in the same manner that genetic systems become relatively tangential with the growth of culture.

Not only is a merging occurring between culture on the one hand and the other two information streams, but the other two streams are themselves getting merged through new developments.

Computers, including those with AI characteristics are being increasingly used in the genetic field to identify, store and analyze genetic information. These vary from the use of computer graphics to picture the molecular structure of genes to the massive use in the Human Genome Project to identify, analyze, sequence and store genetic information.[26] At the initial stages, there would be a human intermediary in such mergings, but increasingly the mass of data and the complexity involved, as in the genome project, would involve using autonomous techniques which would increasingly make humans tangential to the process. In such a case, the identification of a phenotypal characteristic to be eliminated or enhanced would be done through automatic analysis. And in addition, the search in a data base for the required gene to be spliced-in, as well as the act of splicing-in too, could be automated.

After the major genome projects under way are completed, the identification and merging of gene sequences would be, for many purposes, done by non-human means.[27] One could, in fact, conceive of a nearly fully automated system occurring through developments of present-day Computer Integrated Manufacture (CIM) techniques being extended to the genetic field. In CIM, the integration of the material flow with the information flow occurs through computers.[28] Application of such a system to genetic engineering would mean that through a data base, automatic means would do the design (in this case, the genetic design), planning, as well as the actual "manufacture" itself. It is not far-fetched to imagine the desired phenotypal characteristic itself being reached through artefactual information means by using a market research system that is heavily based on computer data bases. The output of the market research would feed into the genetic equivalents of Computer Aided Design (CAD) and Computer Aided Manufacture (CAM). These could all use adaptive systems such as neural networks and genetic algorithms and do their work interacting with the massive data bases of the genome project. Artefactual-intensive market research would then feed the CIM stage giving rise to a highly integrated, near seamless, merging of artefactual and genetic information.

Mergings of the two also occur in the proposals to use biological materials in biochips and molecular switches.[29] Indirect mergings occur through the newer AI techniques which are modelled more or less directly on biological models and include neural networks and genetic algorithms. In the former, computer elements modelled on the neuron form the essential core computing element, while the latter is based on modelling the biological evolutionary process. In all these cases of mergings of the two domains, once the mergings are eventually done either to the artefactual or the biological line, the merged line develops autonomously irrespective of the partial “alien” source of its information.

In the mergings between the two non-cultural streams, there is initially always a silent partner in the form of culture. It is culture, and cultural information that gives the initial template for the transfers between the other two. In that sense, what occurs is actually a partial merging of information from all three sources. In neural networks, the cultural definition of how a neuron works is simplified and built into an artificial model of the process. In genetic algorithms, a cultural definition of how evolution allows biology to come to acceptable solutions in evolution by exchanges among chromosomes where the unsuccessful ones are eliminated, is applied to the machine realm. Here, strings of programming code are allowed to evolve to an acceptable solution.

But one could extend this artefactual evolutionary step still further, at least for the moment in concept, into the biological field. One could conceive of biological genetic solutions being arrived at on dry runs in computer form by getting the strings of programs to actually code for genetic information so that the solution arrived at becomes, in fact, a solution to biology. Such an eventuality would result in dry runs in biology; for evolution in biology to be speeded up and then only the end result of what would have normally taken millions of years delivered after only a few hours of computer runs, to be then realized in biological form as an organism.

Generally, one could now say that the two new technologies allow for the intense merging of the information streams so that for all purposes in the future, biology, culture and artefact have to be seen as one evolving whole. In becoming a single evolving whole, the historical sequence of biology giving rise to culture, giving rise to artefact and each inner core lineage acting as a “hand-in-a-glove” becomes changed. The artefact now reaches back and changes culture or gene, the glove turns back and changes the hand. Instead of a unilinear sequence, a recursive loop is established. Genes now reach back indirectly through the chain of culture and artefact and through them partly redirect their own mixing. Similar recursive loops occur for example from culture to artefact alone when, say, a CAD system’s output helps a human to change its design. These recursive loops help bind the three streams together. They also now become determinants of evolution in all three lineages.

The merging also changes the reaction times to the environment of the two lineages. The later lineage, whether it be culture or artefact, was faster than the earlier one, whether it be respectively gene or culture. With the merging, this sequence of reaction times is disturbed. Because of influences from the outer elements – respectively genetic and cultural – evolution changes faster speeding up their individual lineages. Also, as a consequence, the information of the outer layer which had a relatively shorter life time, now lives longer in the inner one. Because of the greater degree of shuffling of information possible with the merging, the rate of evolution would be speeded up analogous to the speeding up of evolution which was brought about by the introduction of sexual reproduction in the biological field. One could also mention that the merging would also bring about changes in the gestalts, or "world views" encoded in the lineages.

The merged system would therefore result in changes in speciation, memory retention, flexibility and speed of reaction to the environment, hierarchies in nestedness, rates of evolution and "world views".

Now how do aesthetics and the arts come into this process of merging? Mention was made earlier of the intimate relationship that aesthetic factors bring to science at its creative moments. Aesthetics and the fine arts form part of the cultural information continuum, standing beside scientific information as an important part of the battery of intervention mechanisms that humans have with the environment. Hence, in an integrated, merged system one could conceive of the aesthetic factor affecting biotechnology and information technology. Aesthetics help one visualize particular structures in molecules as well as help design better computer hardware and software.

At a less general level one can point out the use of computers in art and design.[30] Computer techniques that graphically display different molecules of genes and proteins are being increasingly used. Some of these techniques identify the Newtonian dynamics of each individual atom in the biological molecule and so try to predict their future. [31] At another level, using computers, a protein engineering data base is being built up which could help visualize and design a variety of biological molecules for specified uses.[32] Using virtual reality systems, wearing a data glove for example, a biologist could get the feel of the different molecules as well as the strengths of the various molecular forces that bind them together. At an apparent trivial level, but with more serious potential as a possible tool of exploration of a merged system, are the efforts being made to transfer DNA sequences into a music formats.[33]

One could eventually imagine a merged system where a human traverses virtual reality exploring different parts of the merged system and, in the process, being influenced by the biological and the artefactual. In the ultimate, it is possible to think of a near-seamlessly linked system where the different boundaries vanish, a change in one affecting the other. Aesthetics becomes biology, turns to an intelligent matrix in an artefact and vice versa. A change in one is reflected in the other. Ultimately the aesthetic becomes, through the intimate play of computer techniques and biology, an integral part of the whole merged system.

The two new technologies encroach directly on the four billion-year history of biology and the, say, ten thousand-year history of human culture. In mixing together the constituents of these two histories into one whole, history as we know it changes dramatically. An entirely new history begins.

## Notes

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