On the Role of Science in the Postindustrial Society "Logos" – The Empire Builder

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PREFACE

In any hierarchical structure of systems, the fundamental causes of observed phenomena are usually outside the system studied and inside the next one up in the hierarchy. The exercise reported here aims at discovering the hierarchical set in which human society is embedded, in order to provide heuristic guidelines in the search for global causes and mechanisms, for the particular area of the economy and for social behavior more generally.

The hypothesis advanced is that syntactic language, and its advanced hypersyntactic form, scientific language, constitute the next step after DNA in information handling, basically preserving the rules of the game. As shown in the report, this hypothesis can lead to a constructive and quantitative outlook in the area of economic processes and technological innovation that is of great interest for IIASA's research on societal changes.

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On the Role of Science in the Postindustrial Society

"Logos"—The Empire Builder*

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ABSTRACT

The hypothesis that language and DNA represent two stages of the same evolutionary path is briefly evaluated. Volterra equations, so useful in describing the dynamics of competing systems are, in fact, equally efficient in describing social behavior, as shown in numerous examples. The emergence of language first, and science later, interpreted as a metalanguage, are attributed to a "hypercyclization" of basic competing utterances in analogy of hypercyclization of quasi-species of replicating molecules in Manfred Eigen's theory of DNA development and evolution.

When one observes the effects of technology and science on our society of the past 300 years, the natural reaction is of astonishment and fear. Aren't we heading at marvellously increasing speed toward the final and definitive crash? I will develop here the very constructive thesis that if we look at evolution at the proper level of abstraction, from the first self-affirmation of replicating molecules to the American empire, the tricks and rules of the evolutionary game were always the same. After all, replicating molecules and Americans were striving for the same objectives: *negentropy, range, and control.*

Looking at the situation from inside the biological systems, to which humanity and science naturally belong, the first two objectives can be seen as external, and the third one as primary and internal. Control is, by the way, the object and indicator we have to analyze in order to reveal the whole plot. Control is a word that is very difficult to define in abstract or general terms. I would define *control* as bringing the out in, which may sound a little strange, but if you think about it a little you may agree with me. A king rules a country and "identifies" himself with it. In other words, he brings it into his ego.

The concept of negentropy is a little easier to define precisely. *Negentropy* is the potential for change. It fuels the organizational drive of life, range, and control. The fight for it is ferocious, as everyone tries to divert the maximum amount of it—self-multiplying molecules in the primeval soup by faster and faster speed of multiplication, and man fighting ever since for arable land and energy resources.

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Concerning *range*, every living species, from the reproducing molecules in the primeval soup to man, is trying to *expand in space* as far as possible. Space exploration, or the conquest of the West, are just outcrops of this fundamental and basic drive. All other rationalizations tend to be poetry.

Incidentally, these three very basic concepts are not really primitive. As Manfred Eigen has shown [1] they, and Darwinism wholesale, descend from the necessary behavior of self-reproducing systems.

Just to lighten up my presentation I will tell you a little story to show how these very general concepts feed into everyday life. A couple of years ago, I conducted a system study about air transportation, and of the necessity to travel in general. I learned something I had suspected, namely, that people do not travel by plane in order to save time, as they usually say. In fact, the analysis of traveling time for people, from Zulus to very sophisticated and rich upper-class Americans, shows that traveling time is basically constant about 65 minutes per day. When people become more affluent what they really do is not reduce it, but allocate an increasing share of these 65 minutes to faster and more expensive modes of travel that permit a broader *range*. So, when people travel by plane they do not buy time, they buy range. And range is used for *control*.

The percentage of income dedicated to traveling is fairly constant, about 13%. And, by the way, income is an excellent proxy for *negentropy*. The only thing we buy with it, in final analysis, is always negentropy.

The principle that guided me in choosing Darwinism for the analysis of Society's behavior is a very simple one; it is that workable ideas are very few. Moreover, Darwin had the luck of hitting onto an idea that could interpret the operation of biological systems for three billion years. If an idea can unify the behavior and evolution of such complex systems for such a long period of time, it must be a really good one.

At the beginning there was the primeval soup, as everybody knows. The Earth had a reducing atmosphere containing ammonia, CO_2, and other things, and a lot of ultraviolet rays; there was also the sea. All these chemicals combined into the numerous organic molecules it is possible to construct just by stochastic combination of radicals and other things. So we start with the soup, and the soup contains the two or three or four keywords, or key-molecules that later gave rise to very complex biological structures. Some of these molecules were bases which, with the help of very simple catalysts can combine to make chains. These chains of proto-RNA had a peculiar property for molecules: *they could reproduce themselves*. Similar component molecules attach to a chain, and make a kind of negative of the chain; the negative makes a positive, and so on. Thus, under proper conditions, the chains can multiply and, in fact, multiply very fast—as demonstrated in experiments made by collaborators of Manfred Eigen—beginning with soups somehow different from the original one, but having many similarities.

I made a back-of-the-envelope calculation and estimated that these self-reproducing molecules in the primeval soup of the ocean could have a mass not very different from the mass of living things today, in the range of a few hundred billion tons of material. The vigor was undoubtedly great since the beginning, but the organization was still poor.

Proto-RNA molecules, which started autocatalytic replication into the primeval soup, actually faced two basic bottlenecks. First, duplication was subject to errors that rapidly destroyed the "ego" if the message was too long. A protospecies of RNA molecules could survive only if the message had no more than a few hundred codons. Errors, on the other hand, were necessary in order to creat different messages. Second, the message was open-ended in the sense that it could not feed back on itself.

Both problems were solved through the invention by RNA of slave molecules, the

proteins that could serve it, e.g., by catalyzing RNA replication, and could carry messages around, readable by other RNAs. The fact that RNA molecules could talk to themselves and to other RNAs opened the way to a fundamental breakthrough. At the beginning, reproducing molecules could express themselves basically by subtracting material from the soup, as I said. A certain successful molecule (or message) would survive as a cohort of mutated offspring with a common hard core kept together by selection. Such a set is formally similar to a species with its genetic pool of mutated individuals, and was called a "quasi-species" by Eigen. Quasi-species could not keep their messages too long, not more than a few hundred letters or the core would be lost through runaway error accumulation. Fighting each other by subtracting soup or components would not have brought them too far. Proteins became the basic intermediate for creating more complex structures through organization. So, information transmission from the beginning appears to be a key-module, a key-element in the organization of the system.

Now the breakthrough in organization was of non-Darwinian character. It was the creation of a coupling between competing quasi-species of molecules into a *hypercycle* where one species was linked to the next through a life or death mechanism.

The working and function of hypercycles has been reconstructed by M. Eigen in a set of absorbing papers [1]. The simplest system is that of a quasi-species, A, producing a chemical, e.g., an enzyme, necessary to the growth of B, and B producing one necessary for A. Then all evolutionary branches where A and B try to destroy each other are automatically eliminated, and A and B can only evolve along "collaborative" paths. Any number of partners can be drawn into the magic hypercycle, but only if the control chain is closed can the system become stable. Open or branched chains are finally destroyed by instabilities. In this domino system every member is protected as its destruction would collapse the whole set.

The great evolutionary advantage of the hypercycle is in fact, that the amount of information that can be handled is much larger, by one or two orders of magnitude. This is so because many quasi-species *pool* their (noise-limited) messages into a single one. In anthropomorphic terms, this is the principle of hierarchization. Thus, to the original principle of Darwinian competition another principle has been superposed: that of hypercycle organization and hypercycle collaboration. If we look, just to make a jump ahead, at social systems, we see, e.g., that the President of France is controlling the French people through a complex chain of hierarchical organizations. He is, however, ultimately elected by the public itself, which, in a sense, closes the loop and points to hypercyclic control of the social system and the many formal analogies with the hypercycle that controls, for instance, the genetics of collaborating quasi-species.

Because now hypercycled quasi-species behave again as a (quasi)-species—albeit more complex—the game can be repeated through a second level hypercycling or hierarchization and so on. The great tricks were established three billion years ago and are neatly delineated: Darwinian competition and non-Darwinian collaboration through cross-control followed by hierarchization. After three billion years of magnificent success, their potential is far from exhausted.

In this light, the logic of the evolutionary steps appears self-consistent and meaningful; the steps appear to have an enthelekeia, a final purpose. Just to highlight some of the breakthroughs, the creation of a skin to separate the "in" can be interpreted first as a noise suppressor in the communication between hypercycled RNAs, selecting out interfering chemicals from other communicating systems, and only later assuming the function of preserving a stable physicochemical habitat for the cell machinery that could then become increasingly subtle and complex. The city was walled. The next step was

to build the imperial palace. It was, in fact, the eukariotic breakthrough to enclose the DNA machinery in a nucleus, where a higher degree of hierarchization in information handling could be reached. Thus, the nucleus' wall separates the *imperatoria brevitas* of executive orders sent out to the operational machinery of the cell from the abstract and lengthy mandarin reports circulating inside the sacred barrier. Very long strands of RNA do, in fact, circulate inside the nucleus of eucariotic cells, their function being not yet clear to biologists. They are most probably of a regulatory character and certainly not directly related to transcodification into proteins. This novel step permitted the manipulation of three orders of magnitude more information so that metazoa, i.e., large sets of cells organized through hypercyclic controls, became possible and actually appeared perhaps a billion years ago.

We belong to the metazoa, and with a little pride we may think we are the diamond tip of that class of living objects. Biologically we do not differ much from the others, incidentally our chemistry and genetics is very marginally different from that of the Chimps, but the old trick was formally played once again in another direction.

Animals communicate with each other in many ways, chemically most of the time, but through modulated sounds, in particular. The messages are usually short and convey basic features: love, hate, fear, possession, and dominance. Their structure and function make them formally similar to the molecular quasi-species competing in the primeval soup, and one has simply to sit in a tropical forest and listen, to become aware of this analogy.

What actually happened with man is that single messages—let's call them words or short sentences—were organized in a hypercycle so that they could interact and collaborate instead of compete. The action of the verb is lost without a subject and an object, and a subject is dead without the verb and the purpose of the object. *Syntax* channels the feedbacks and keeps the structure operational. A new hierarchy is introduced, and the barking of the wolf in a mere few million years becomes the oratory of Cicero in the forum, in the same sense as the loose quasi-species of molecules dissolved in the primeval soup became the protoprocaryotic cell.

Organized language is a new hierarchical level in the handling of information, or more precisely, in the exploration of new "viable" structures. The check for viability, however, requires servant structures, like the old proteins, to go out and take the scorches of real life. If they come back at all they are good, as Darwin said. If not, they will still serve the precious purpose of telling that they are not good. The equivalent of proteins in this case is as abstract as words, and they are actions. When they are somehow sophisticated, one calls them experiments. And here comes science. Science is different only because it imposes a very strong syntaxis to the interaction between the world of structures created in the language realm and the world of structures explored by the experiment. An animal is also an experiment devised to check the consistency between the structure coded in its genes and the constraints of the "external" world.

Science has been defined, at various times, as a meta-language, the meta—in our optics—meaning, presumably, a higher hierarchical level with respect to current language in the process of hypercyclization. This level, I suspect, basically reduces noise, by digitizing concepts against logical grids from which particular templates are extracted. In this view axioms and logic provide the grid for mathematics, the grid being made by the set of all possible logical structures compatible with the axioms. When messages can be kept highly free of errors, they can be very long, and consequently complex, without loosening their grip.

Because of the complex features, a hypercycled language has the potential of mastery. Its control of man, the phenomenon of society kept together and controlled by the next hierarchical structure we anthropomorphically define as culture, can be considered the next step after metazoa, man having most of the features of the cell in (primitive) metazoa.

When observing that metazoa, which belongs to different species, can fight to kill, it becomes clear that war is basically an expression of intercultural competition. When trying to explain why man is the only animal that destroys individuals of the same species, Lorentz reaches exactly the same conclusion [2].

If the game is the same, then the mathematics of genetics and ecology could be transplanted into the description of human affairs. Doing that has been an inexhaustible source of fun and amusement for me, and the core of my work at IIASA during the last seven years. I can show a few examples here, randomly chosen out of a vast portfolio. My godfather was Heraclitus who said: Πόλεμοζ πάντων μὲν πατήρ ἐστι, πάντων δὲ βασιλεύζ. In modern language, "Competition is the creator *and* the regulator." The world can be perceived as an assembly of dynamically competing structures. Dominance is the final measure of quality.

Figure 1 demonstrates the growth in time of a population of *bacteria* in a broth. Just by changing the time scale we get the growth of the *car* population in a certain area. The points reported in the figure refer specifically to Italy.

Figure 2 describes the "colonization" of the brain of a child by language, taking the operational vocabulary as a proxy for the level of colonization.

Figure 3 shows the "colonization" of the United States by paved roads, using their total length as a proxy.

Figure 4 shows that bacteria exhaust their broth from edible molecules in the same way as chemists exhaust the external world of discoverable elements.

Figure 5 indicates that the same occurs if inventors explore the variegated world of all possible machines chasing the more efficient ones.

Figure 6 shows primary energy sources, and Figure 7 shows particle accelerators, both competing for customers, i.e., colonizing a certain econiche called the market.

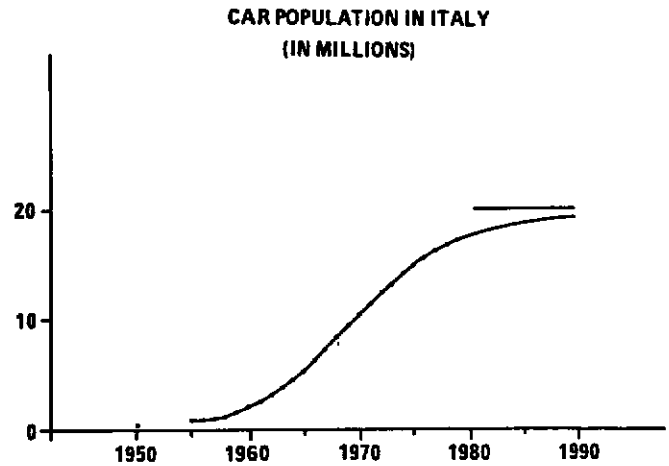

Fig. 1. The simplest solution of the Volterra–Lotka equation is the logistic curve describing growth, e.g., that of a strain of bacteria in a limited environment. It describes equally well the growth of a car population in a geographical area—Italy in this particular case.

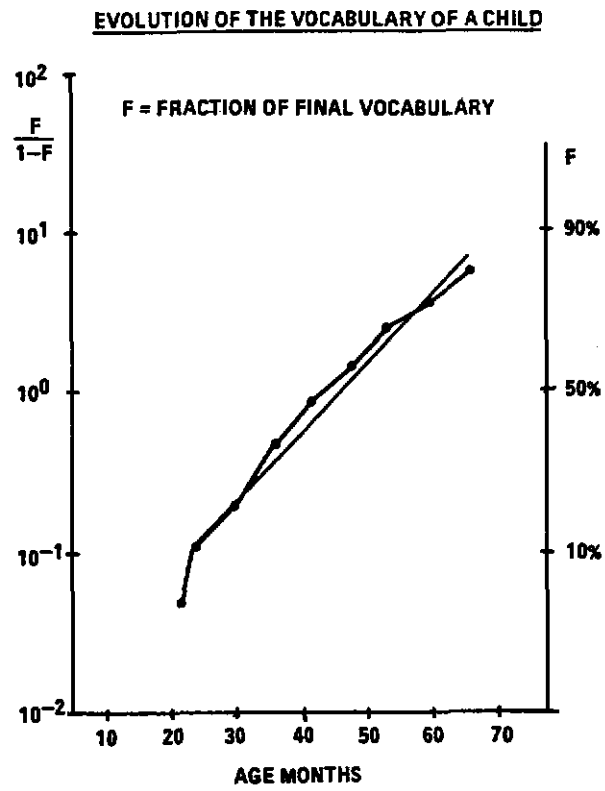

Fig. 2. Looking at the brain of a child as an econiche, learning a language can be perceived as a form of colonization. Taking the operational vocabulary as an indicator of the evolution of the process, we obtain the above logistic. Learning processes appear to always behave that way [7].

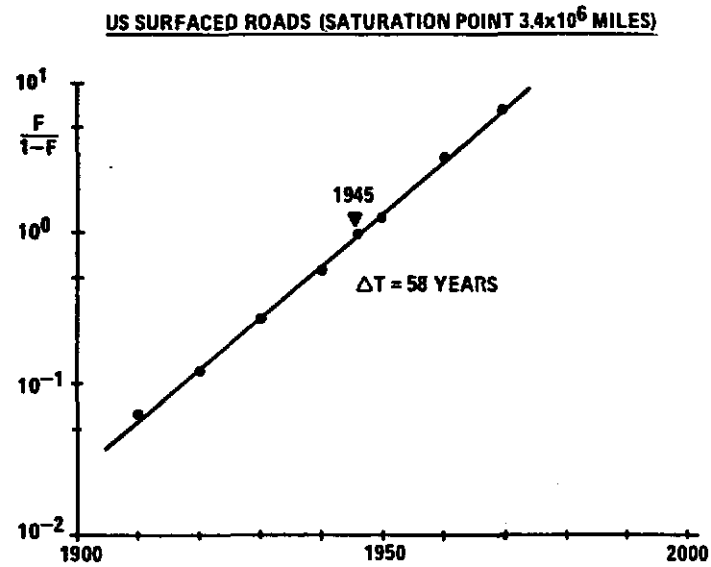

Fig. 3. Just as the iphae of a fungus invade a piece of bread, paved roads spread over the surface of a country. The particular abscissae are for the United States. The equation is always the same.

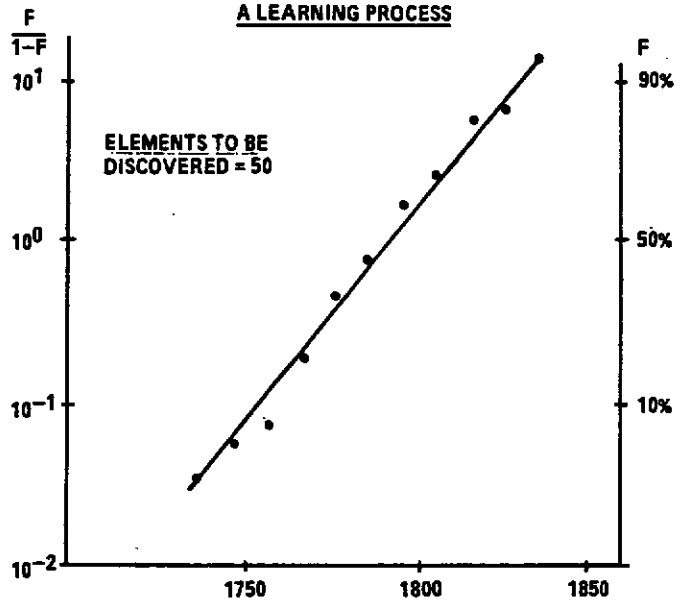

Fig. 4. Mental configurations explore the external world in search of matching structures. This is formally equivalent to a colonization. At any rate, the mathematics is identical, as the discovery of stable elements by chemists in the 18th and 19th century clearly shows.

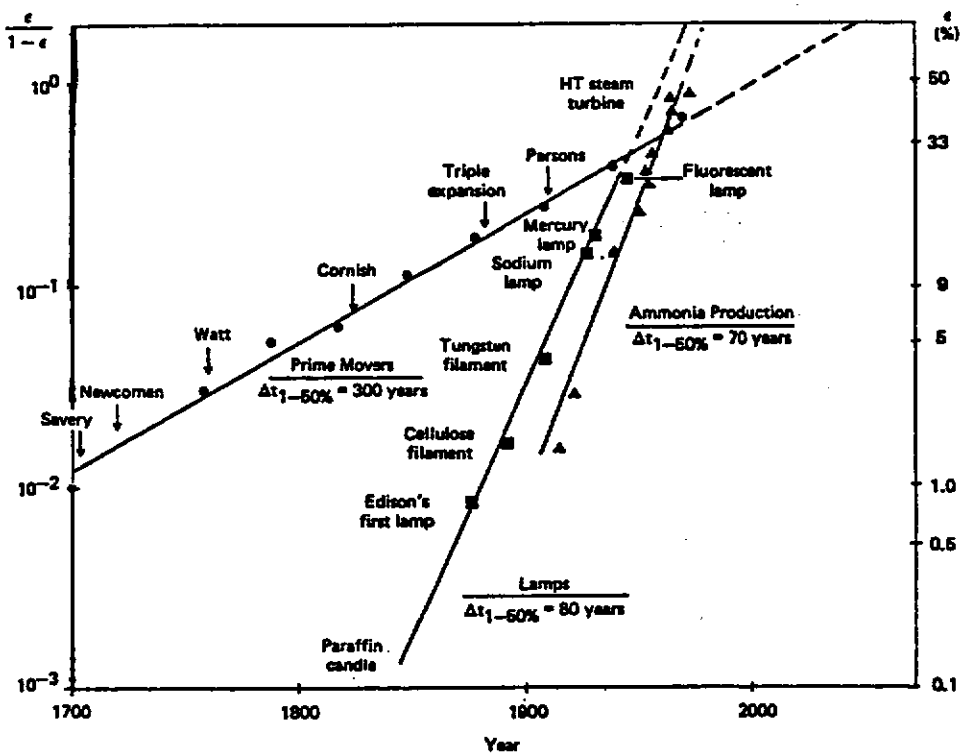

Fig. 5. Mental configurations can also explore *possible* external configurations. We are dealing here with machines for energy transformations, and the strive of inventors is charted through an optimized boundary condition, second-law efficiency. Here too, the equation is the same and the colonization takes 600 years—all uphill.

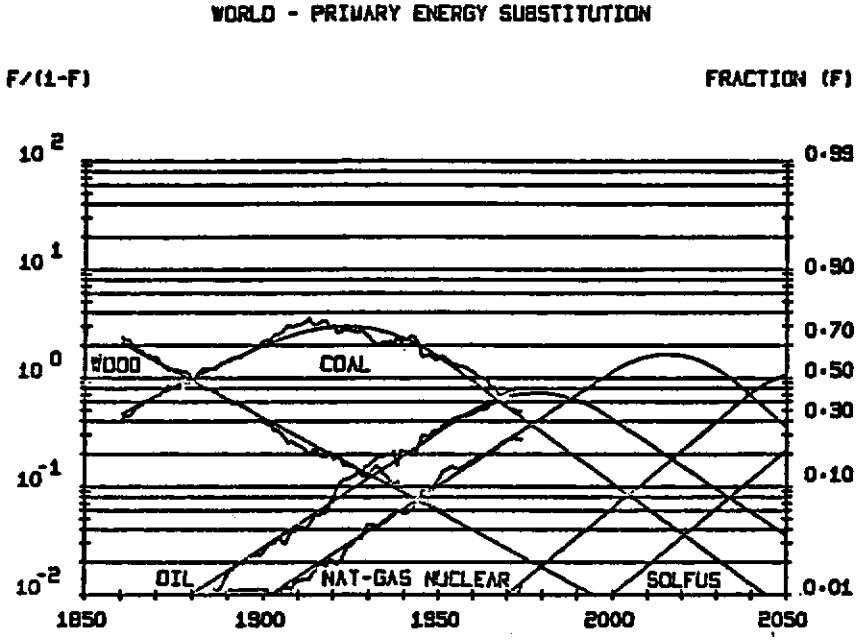

Fig. 6. Primary energy sources can be seen in many ways. Here they are considered as new technologies, colonizing a market, just as new species colonize an econiche. The mathematics is the same.

Figure 8 is a testimony of my absolute loss of restraints in the analysis of structures. Here I assumed that causes of death by category can be assimilated by enterprising undertakers competing for business. Some are better and bag an increasing share of carcasses. The competitors I zoomed in are cardiovascular vs. neoplastic diseases (in the United States). Neoplastic seems the good bet, creeping to victory in the long run.

I stop here with examples for obvious reasons. We worked out about 400 of them, ranging from air traffic to invention and innovation, or the price of energy. Volterra–Lotka equations, which are central to ecology and genetics, fit everything beautifully [3–5].

At this point the skeleton logic has been set up to frame the question giving the name to this conference: What is the role of science in postindustrial society. In passing, I would like to redefine this postindustrial society. Industry will keep existing as long as food production does, but a decreasing share of the population will be employed in it, as has already happened with agriculture in developed countries. The process may take the usual couple of hundred years, and, thus, it has to be seen as a dynamic continuum. So, I would rephrase the question to: "What is the role of science," *tout court,* or adding at most "in society," but dropping the postindustrial.

As I tried to show, science can be seen as a meta-language for the exploration of the external world, creating structures to be tested by experiment. Or in a more stimulating way, as the last hierarchical level of hypercyclization of living structures—the highest and the youngest. Language and meta-language are in fact a few million years old, while the stabilization and exploitation of an essential step in evolution, like eucariotes or metazoa, took a good billion years.

To make a long story short, I would say that *the major objective of science is to gain power* over the biological world, and over the external world, bringing it "in" through control.

To give a little example, genetic engineering and scientific ethics are the talk of the

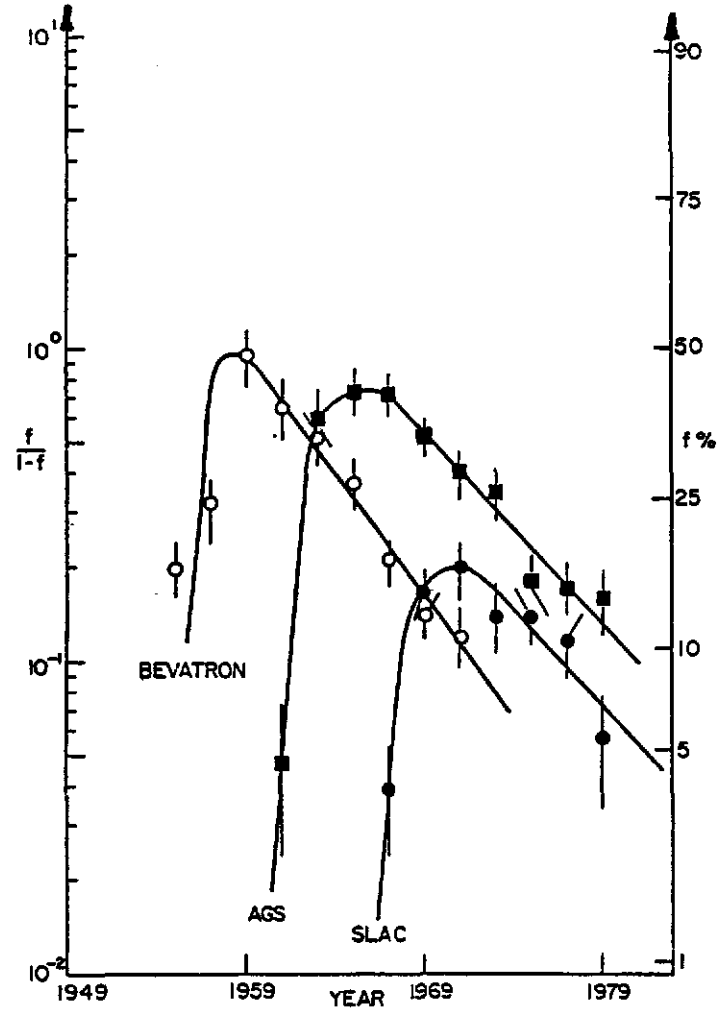

Fig. 7. Just as icecream peddlers, large particle accelerators compete for customers. They can be considered mutants. They come and go in the same way. ***From:*** **T. W. L. Sanford.**

town. In the frame I constructed, genetic engineering is a natural and inevitable step of *Logos* taking control over DNA.

Science then becomes the regulatory agent, like the handling of mandarin reports inside the walls of the eucariotic nucleus, with an enormous potential for penetrating configurations otherwise inaccessible to the restricted creeping of mutation-selection processes.

In the same way as plain language and culture attached complex tools to the hands of man, science will mesh DNA-controlled with logos-controlled structures in an undreamed of new wave of speciation. In the logic of my framework this is not futurology, but a necessary consequence in the same sense that in Eigen's theory the drive for negentropy, range, and control is a necessary consequence of self-reproduction.

To switch the subject a little, some years ago I wrote a paper, mostly to tease my friends in the Club of Rome, showing that technically the Earth could host 10^{12} people [6] in plenty and richness, even meeting the whims of fastidious ecologists. Since self-

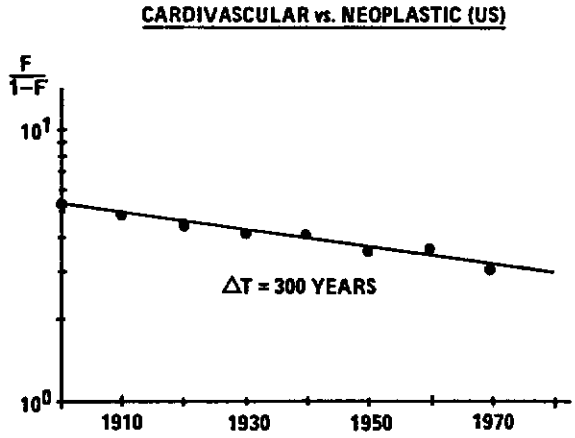

Fig. 8. One can see humanity as a large broth in which somber configurations, such as illnesses and bacteria, fight and thrive. Their activity can be measured, e.g., in numbers of kills they bag. I made the grim analysis of the competition between cardiovascular and neoplastic diseases. It seems to work.

reproducing things appeared on Earth, it never happened that an econiche was left half empty. If I am right, humanity will grow to 10^{12}, and Logos will take care of the details, as DNA always did at the strictly biological level.

I wish to conclude with a very constructive example. Through vigorous hypercycling, science is striving for unity and uniqueness. Cultures are looser and do not do so. In fact, they fight each other in a Darwinian way, the strongest trying to stamp out the weaker ones through various forms of war. Many individuals and organizational structures are expanding their ranges to world level, across cultural boundaries, networking the whole system. This may well be a prelude to a culture hypercyclization, eliminating war and permitting the *sheltered and interactive* development of a variety of cultures, giving richness and power to the whole system. Science may help here to accelerate the process by interpreting it. The so-called free will of humans is, finally, not so important. All my analyses demonstrate the overwhelming strength of the system and the determinism that comes from its homeostatic controls. After all, our position in relation to Logos is not very different from that of the cells in relation to the superstructure of the metazoa. The thrilling part of all this is that we are just at the beginning. The world to explore is vast, the team is strong, we will have guaranteed fun for the next billion years. I will forget to mention the sweat, the blood, and the tears.

References

1. Eigen, M., and Schuster, P., The Hypercycle—A Principle of Natural Self-Organization. Part A, Emergence of Hypercycle. Naturwissenschaften, 64(11), 541–565 (1977); Part B, Abstract Hypercycle. Naturwissenschaften, 65(1), 7–41 (1978); Part B, Realistic Hypercycle. Naturwissenschaften, 65(7), 341–369 (1978). Also reprinted by Springer-Verlag, Berlin-Heidelberg-New York (1979).
2. Lorenz, K., *On Aggression*, M. K. Wilson, trans., Harcourt-Brace-Jovanovic, New York (1974).
3. Marchetti, C., and Nakicenovic, N., The Dynamics of Energy Systems and the Logistic Substitution Model. RR-79-13. International Institute for Applied Systems Analysis, Laxenburg, Austria (December 1979).
4. Marchetti, C., Society as a Learning System: Discovery, Invention, and Innovation Cycles Revisited. Techno. Forecast. Soc. Change 18, 267–282 (1980).
5. Marchetti, C., The Evolution of the Energy Systems and the Aircraft Industry. Chem. Econ. Engin. Rev. 7–13 (May 1980).
6. Marchetti, C., On 10^{12}: A Check on Earth Carrying Capacity for Man. RR-78-7. International Institute for Applied Systems Analysis, Laxenburg, Austria (May 1978).
7. Carlson, R. O., Adoption of Educational Innovations, University of Oregon Eugene, OR (1965).

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