ON THE ROLE OF SCIENCE IN THE POST-INDUSTRIAL SOCIETY: "LOGOS" - THE EMPIRE BUILDER

Cesare Marchetti

January 1982
WP-82-6

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

ABSTRACT

The hypothesis that language and DNA represent two stages of the same evolutionary path is briefly evaluated. Volterra equations, so useful to describe 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.

ON THE ROLE OF SCIENCE IN THE POST-INDUSTRIAL SOCIETY: "LOGOS" - THE EMPIRE BUILDER

When one observes the effects in the last three hundred years of technology and science on our society, 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. It is control, by the way, the object and indicator we have to analyze, to reveal the whole

---

Based on the keynote address at the conference on "The Role of Science in Post-Industrial Society", held at St. Paul de Vence, France, 19-21 May 1981.

plot. Control is a word which is very difficult to define in abstract terms, general terms. I would define control as bringing the out in, which may sound a little strange, but if you think a little about it 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, everybody trying to divert the maximum amount of it. Selfmultiplying molecules in the primeval soup by faster and faster speed of multiplication, and man fighting since ever for arable land and energy resources.

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. The 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 selfreproducing 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 made a system study about air transportation, and of the necessity to travel, in general. And 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 and about 65 minutes per day. When people get richer, what they really do is not to reduce it but to allocate an increasing share of these 65 minuts to faster and more expensive modes of travel which 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 the behavior of society is a very simple one and is that ideas that work are very few. And Darwin had the luck of hitting into an idea which could interpret the operation of biological systems for three billion years. If an idea can unify the behavior and the 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, and there was the sea with water. All these chemicals combined into the numerous possible organic molecules that can be constructed 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 which later gave rise to the 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 and the negative make a positive, and so on. Thus, under proper conditions the chains can multiply and in fact multiply very fast as experiments made by collaborators of Manfred Eigen, starting from soups somehow different from the original one but having many similarities, show.

I made a back-of-the-envelope calculation and estimated that these self-reproducing molecules into 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 that started autocatalytic replication into the primeval soup actually faced two basic bottlenecks: duplication was subject to errors which rapidly destroyed the "ego" if the message was too long. A protospecies of RNA molecules could only survive if the message had no more than a few hundred codons. Errors, on the other hand, were necessary in order to create 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 which 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 subtracting material from the soup, as I said. A certain successful molecule (or message) would survive as a cohort of mutated off-spring 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 by Eigen a "quasi-species". Quasi-species could not keep their messages too long, a few hundred letters or so, or the core would be lost through run-away 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 <u>hypercycle</u> 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 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 kill 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 the system becomes 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 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, to social systems, we see, e.g. that the President of France is controlling the French people through a complex chain of hierarchical organizations, but he is finally elected by the people itself, which, in a sense, closes the loop and points to the social system being controlled by a hypercycle that has 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--if 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 magnificient success, their potential is far than 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 which 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 into a nucleus, where a higher degree of hierarchization in information handling could be reached, separating the imperatoria brevitas of executive orders sent out to the operational machinery of the cell, from the mandarin reports, abstract and lengthy, circulating inside the sacred walls. Very long strands of RNA do in fact circulate inside the nucleus of eucariotic cells, their function being not clear to biologists, but most probably of regulatory character, certainly not directly related to transcodification into proteins. This novel step permitted manipulating 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 in particular through modulated sounds.

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 just to sit and listen in a tropical forest to get the revelation of the analogy.

What happened really with man is that single messages--let's call them words or short sentences--were organized in a hyper-cycle 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 quasispecies of molecules dissolved in the primeval soup became the proto-procaryotic 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 inter-

action 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, at various times, been defined as a meta-language, the meta--in our optics--meaning presumably a higher hierarchical level by 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 from errors, they can be very long, and consequently complex, without loosening their grip.

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

Because metazoa, belonging to different species, can fight to kill, in this light it becomes clear that war is basically an expression of intercultural competition. When trying to explain why man is the only animal which kills inviduals 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 here a few examples, randomly chosen out of a vast portfolio. My godfather was Heraclitus who said: Πόλεμος πάντων μὲν πατήρ ἐστι, πάντων δὲ βασιλεύς. 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.

Fig. 1 shows 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.

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

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

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

Fig. 5 shows that the same occurs if inventors explore the variegated world of all possible machines chasing for the more efficient ones.

Fig. 6 shows primary energy sources, and Fig. 7 particle accelerators, both competing for customers, i.e. colonizing a certain eco-niche called the market.

Fig. 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 to entreprising 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 US). Neoplastic seems the good bet, creeping to victory in the long run.

I stop here with examples for obvious reasons of time. 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 beautifully everything [3,4,5].

At this point the skeleton logic has been set up to frame the question giving the name to our conference: What is the role of science in the post-industrial society. I would like in passing to redefine this post-industrial society. Industry will keep existing as food production does, but a decreasing share of the population will be employed in it, as 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 main 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 is the talk of the town about scientific ethics. In the frame I constructed, genetic engineering is a natural and inevitable step of Logos taking control over DNA.

Science becomes then 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 as 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 selfreproducing 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.

My time slot is reaching the end, and I want to wind up with a very constructive example. Through vigorous hypercycling science is striving for unity and uniqueness. Cultures are looser and do not. They in fact 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 range to world level, across cultural boundaries, networking the whole system. This may well be a prelude to a cultural 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 socalled free will of the humans is finally not so important. All analyses I made show the overwhelming strength of the system, and the determinism that comes from its homeostatic controls. And 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. Because we are at the beginning of the day, I will forget to mention the sweat, the blood and the tears.

REFERENCES

[1] Eigen, M., and P. Schuster. 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. (Wilson, Marjorie K., transl). On Aggression. Harcourt-Brace-Jovanovic, New York (1974).

[3] Marchetti, C., and N. Nakicenovic. 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. Technological Forecasting and Social Change 18, 267-282 (1980).
Also reprinted as RR-81-29. International Institute for Applied Systems Analysis, Laxenburg, Austria (November 1981).

[5] Marchetti, C. The Evolution of the Energy Systems and the Aircraft Industry. Chemical Economy & Engineering Review, pp. 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. Eugene. University of Oregon (1965).

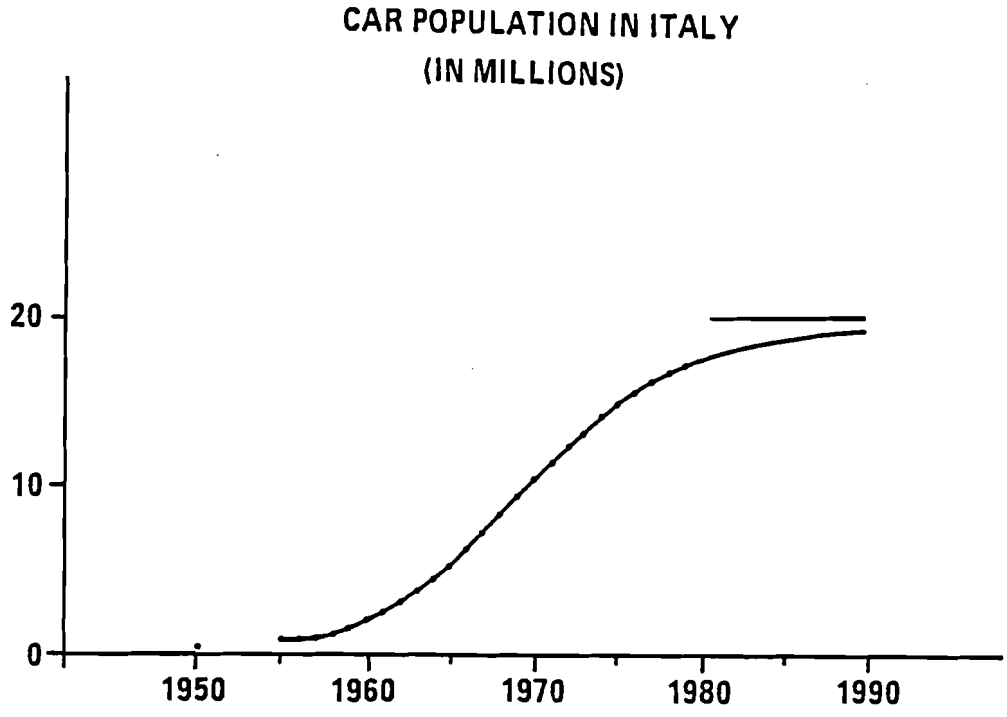


Fig. 1. The simplest solution of the Volterra-Lotka equation is the logistic curve which describes well the growth, e.g. of a strain of bacteria in a limited environment. It describes equally well the growth of car population in a geographical area. Italy in this particular case.

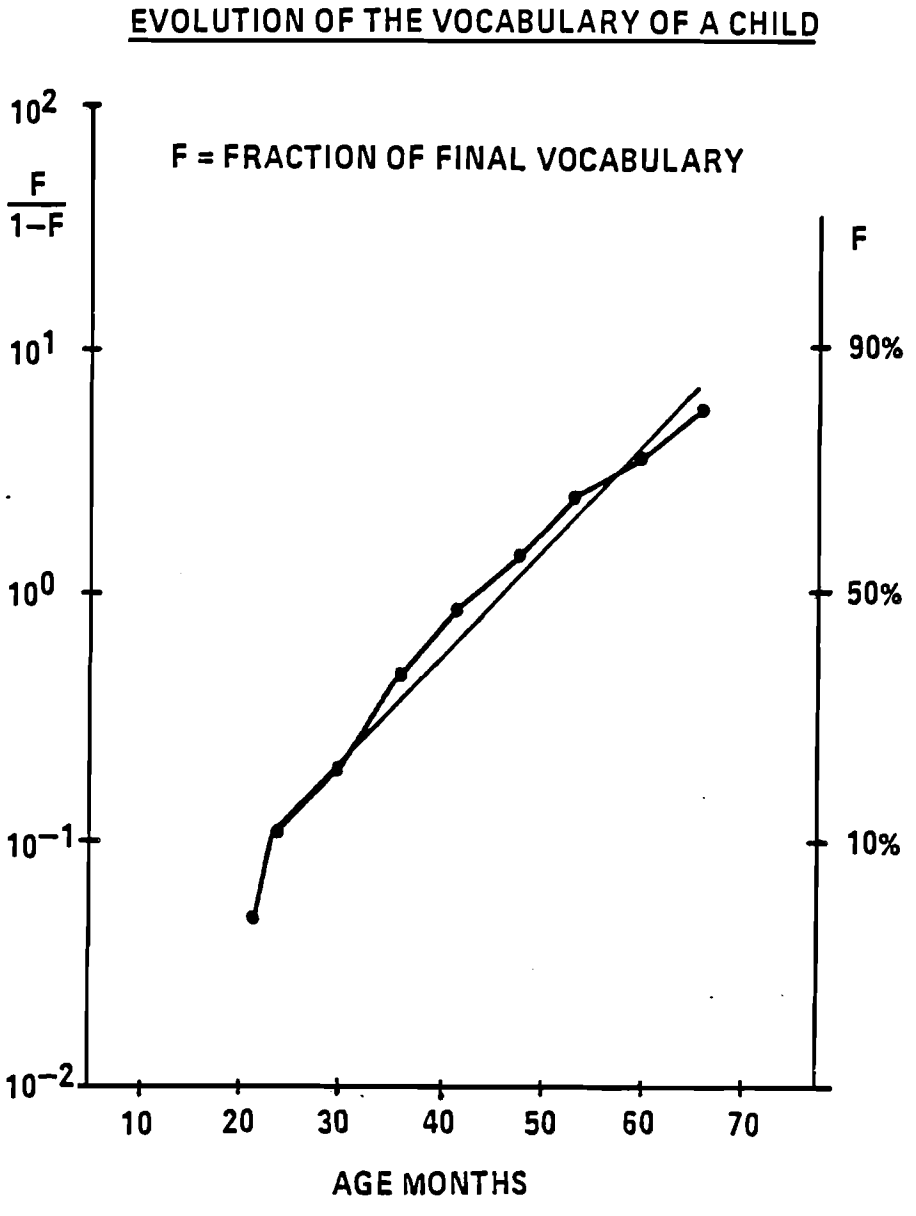


Fig. 2. Looking at the brain of a child as an eco-niche, learning of a language can be perceived as a form of colonization. Taking the operational vocabulary as indicator of the evolution of the process we obtain the above logistic. Learning processes appear to behave always that way [7].

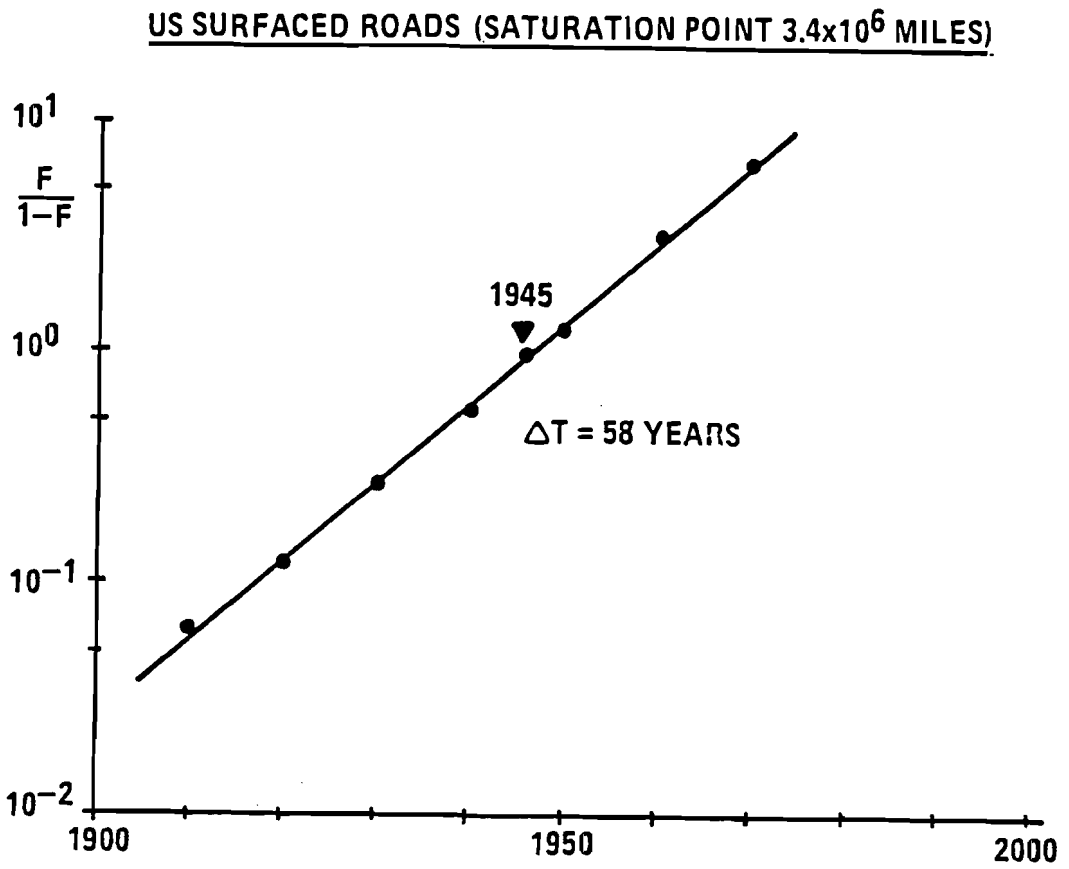


Fig. 3. Just as the iphae of a fungus invade a piece of bread, paved roads spread over the surface of a country. The particular abscissae are for the US. The equation is always the same.

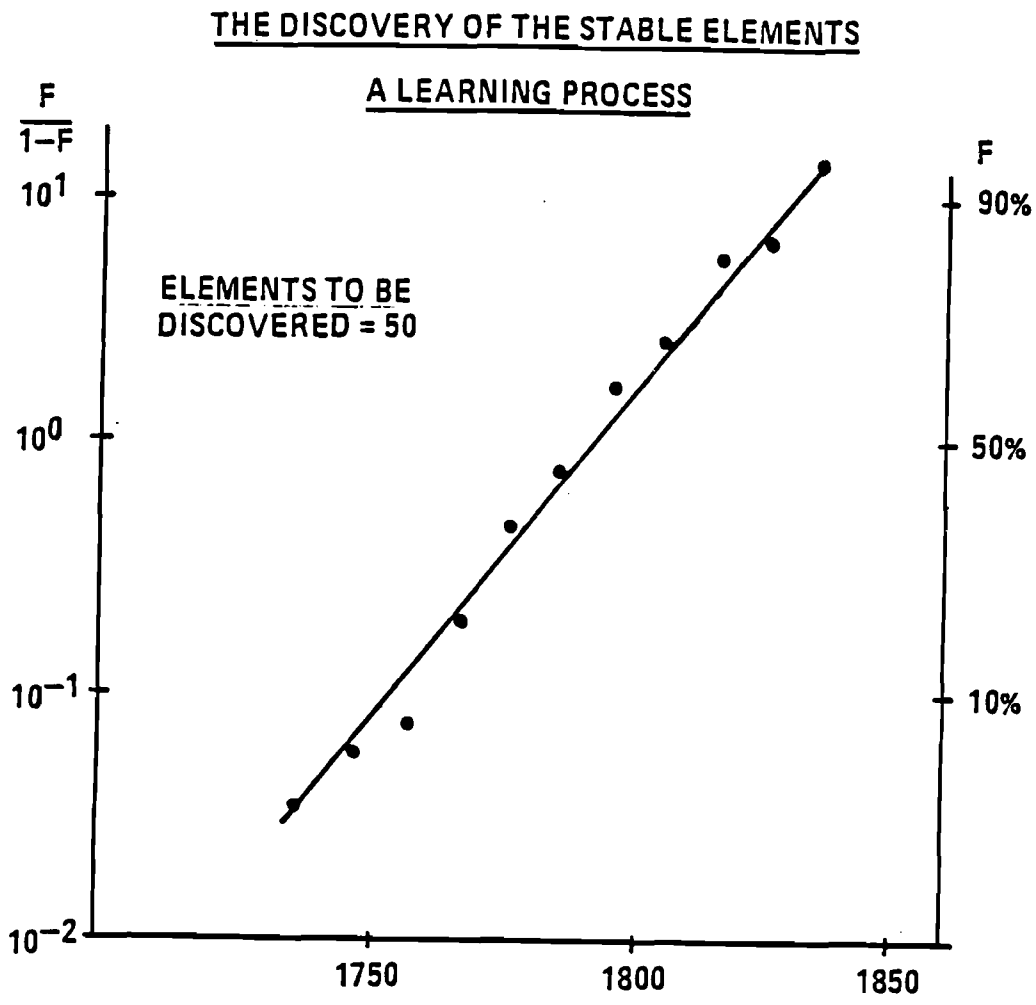


Fig. 4. Mental configurations explore the external world in search for matching structures. This is formally equivalent to a colonization. At any rate, the mathematics is identical, as the discovery of stable elements by chemists in the 18th and 19th century clearly shows.

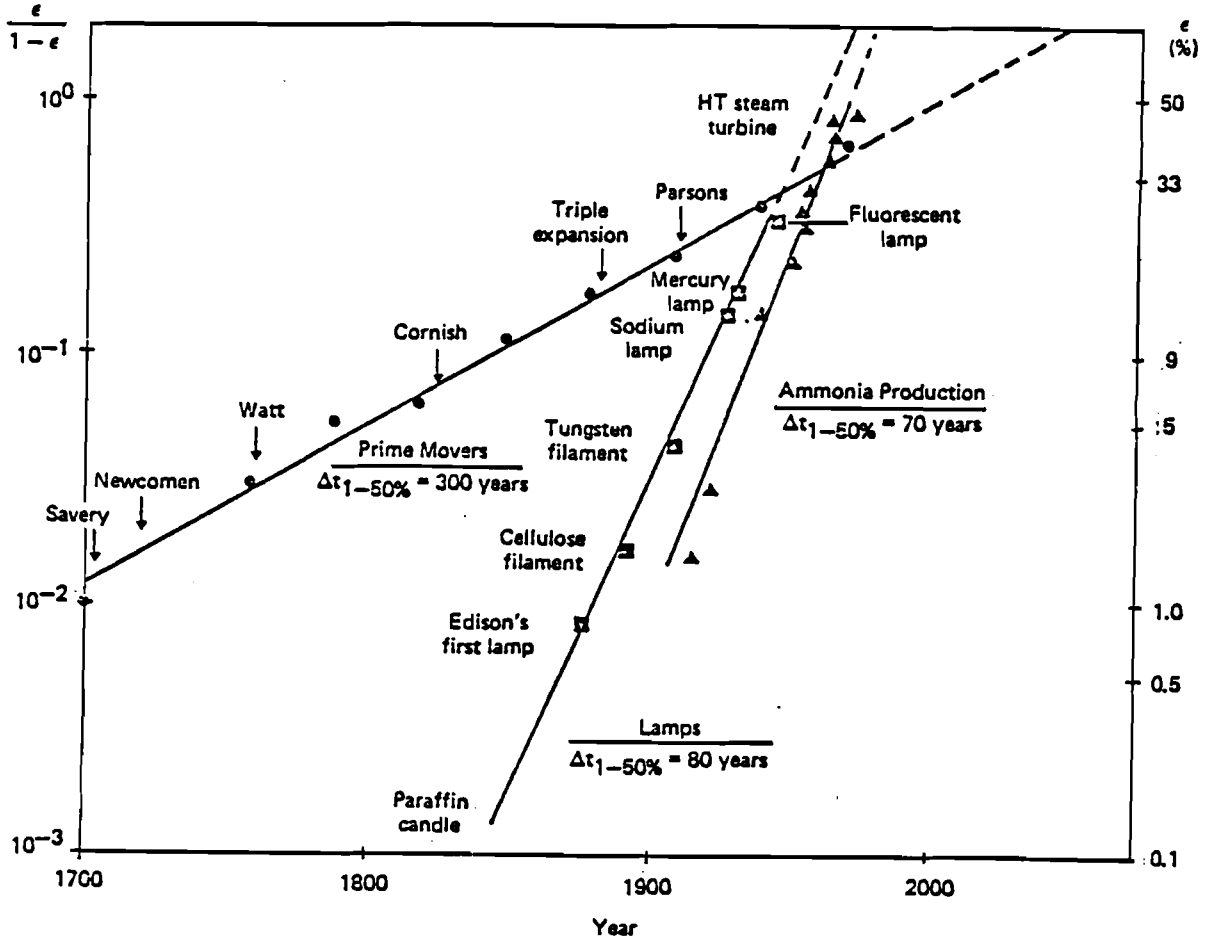


Fig. 5. Mental configurations can also explore possible external configurations. We are dealing here with machines for energy transformation, and the strive of inventors is charted through an optimized boundary condition, second-law efficiency. Here too, the equation is the same. And the colonization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

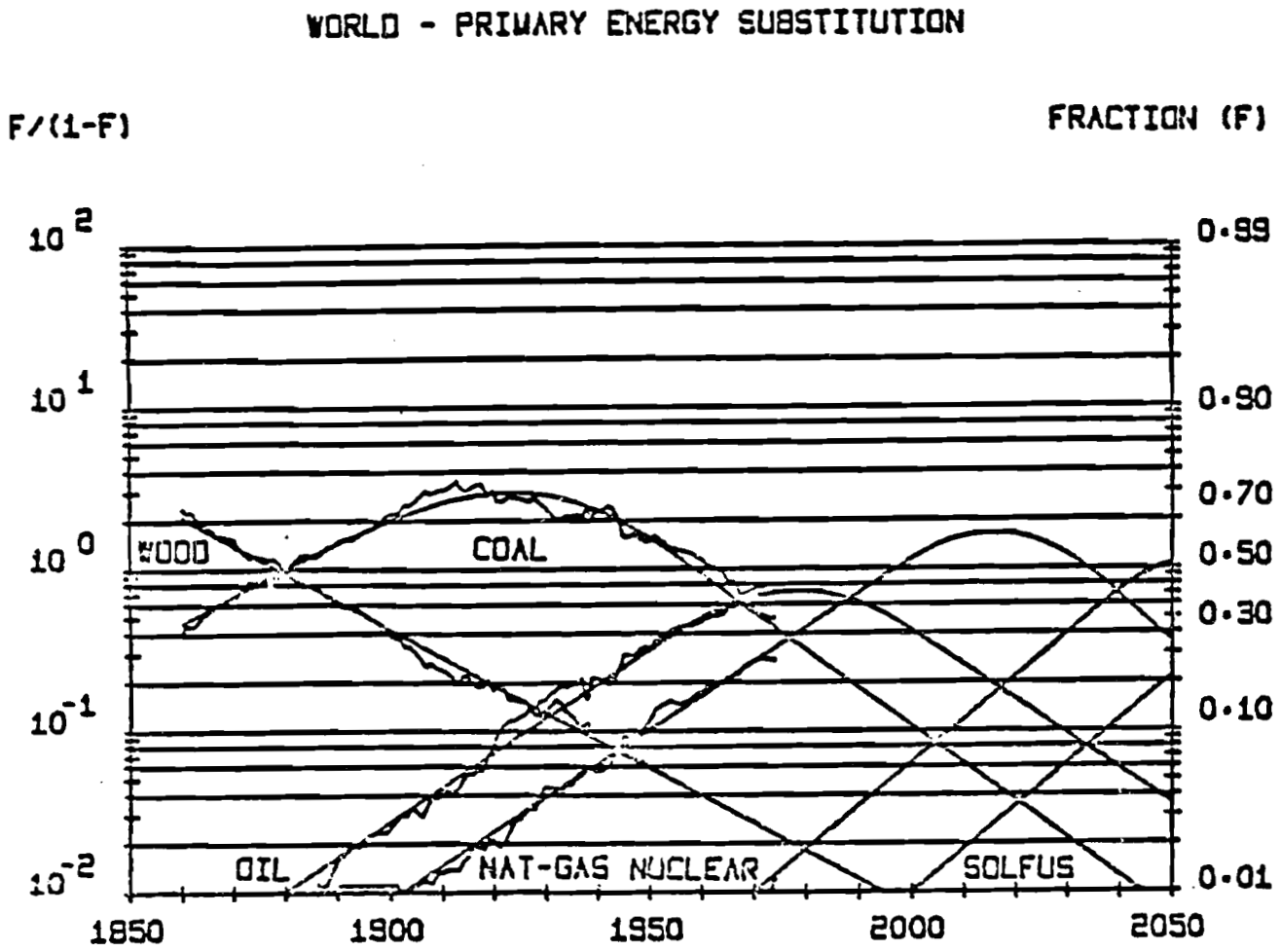
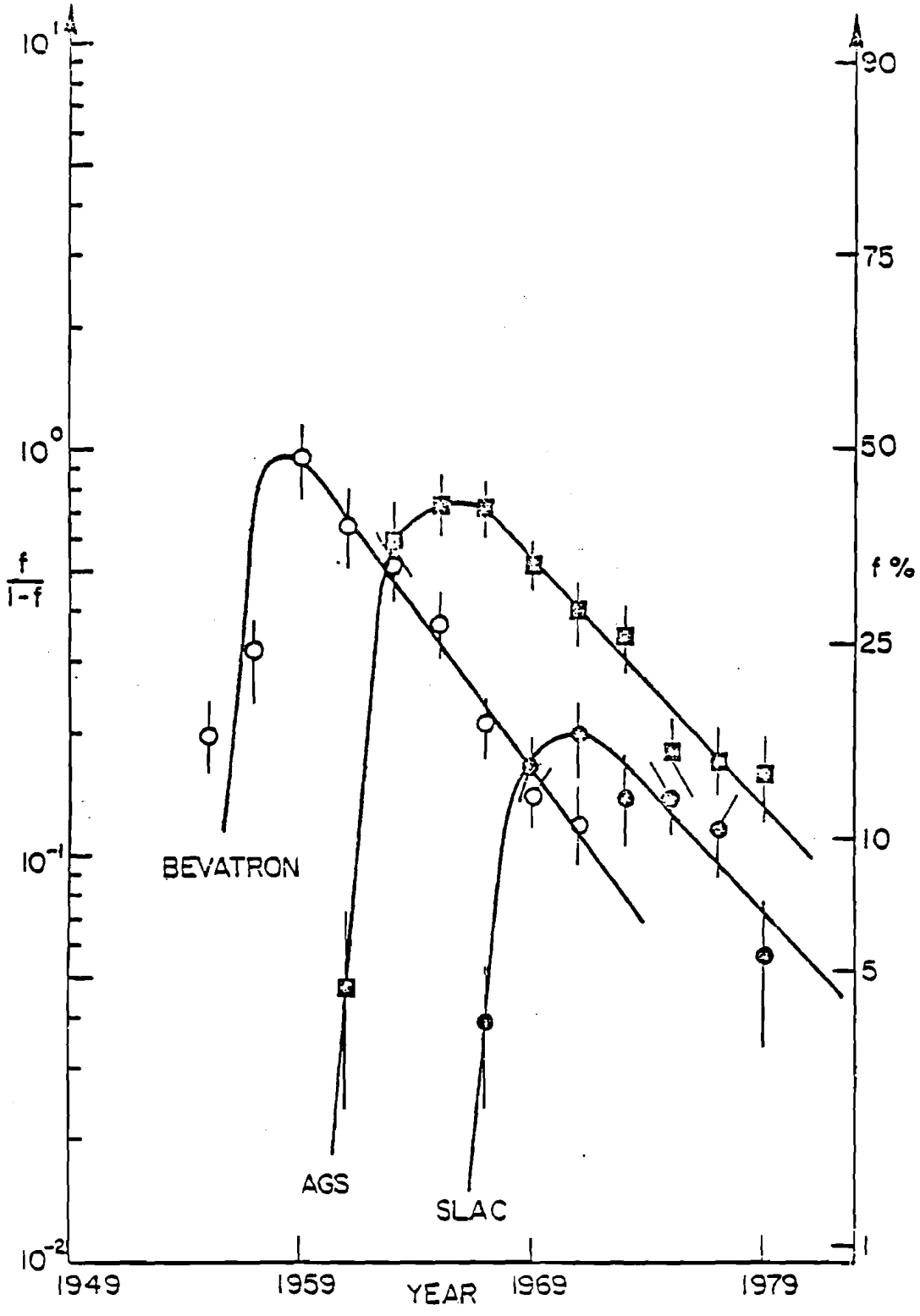


Fig. 6. Primary energy sources can be seen in many ways. Here they are considered as new technologies, colonizing a market, just as new species colonize an eco-niche. The mathematics is the same.



From: T.W.L. Sanford

Fig. 7. Just as icecream peddlers, large particle accelerators compete for customers. They can be considered as mutants. They come and go in the same way.

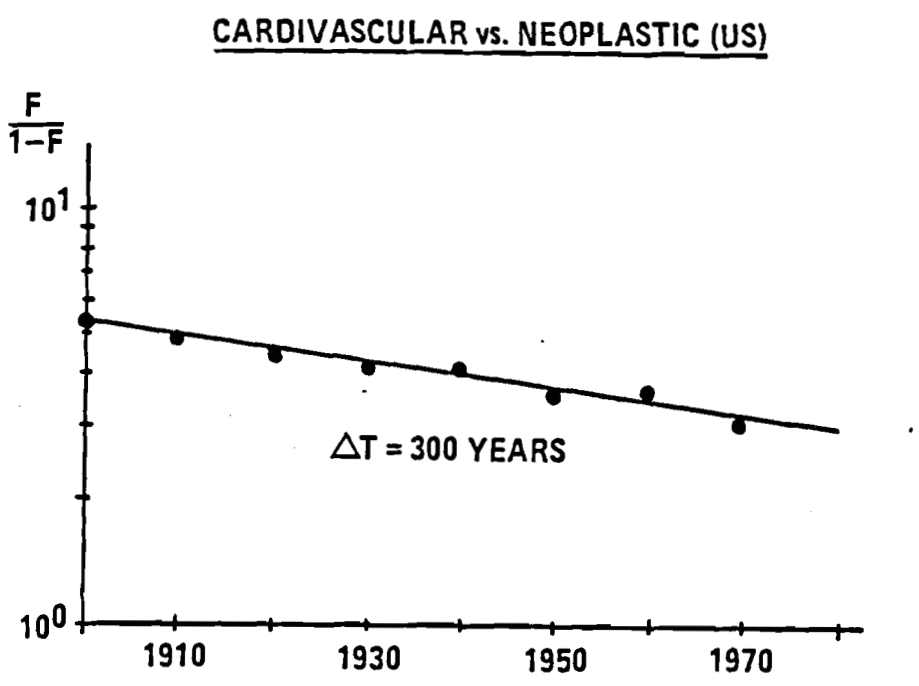


Fig. 8. One can see humanity as a large broth in which somber configurations, such as illnesses and bacteria, fight and thrive. Their activity can be measured e.g. in numbers of kills they bag. I made the grim analysis of the competition between cardiovascular and neoplastic diseases. It seems to work.