Technological Development in History

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Abstract**:** From its origins, the human species has been characterized by its ability to develop tools and artifacts of various kinds. This article provides an introduction to the question about the logic of technological development in Western history. The central question that the article addresses is: "are techniques developed through the revolutionary or evolutionary path?" Does it progress through sudden or abrupt jumps, or through slow incremental changes? The article is divided into three parts. In the first, we summarize the interpretations of the revolutionary and evolutionary history of technology. Next, we reconstruct the typology proposed by Serres to characterize technological development through a model that overcomes the dichotomy revolution / evolution. Finally, we show how these approaches to the history of technology influence the formulation of theories of technological change.

Keywords: History of technology, technological change, philosophy of technology

Throughout history, technics have played a central role in the configuration of the material and cultural life of peoples. To a great extent human progress has been based on the invention of procedures and mechanisms for the resolution of concrete problems in everyday life. From the first techniques of lighting a fire to the complex machines of the modern world, human beings have benefitted from the technical developments, the appearance and gradual refinement of which have deeply marked the modes of social organization as well as the cultural and traditional heritage of civilization.

However, it is not an easy task to understand the nature of technological development. This is due to the fact that the study of the role of technics in history is not exhausted in an examination of the theoretical bases for the construction of machines or in the examination of the functioning of some concrete machines. In fact, technics is also a fruit of the complex dynamics in which very diverse political, cultural and economic factors intervene. Furthermore, technics is not just one phenomenon that occurs in history but also, at the same time, a decisive factor of historical change. In this sense, to understand the nature of technological development it is necessary that we analyze the question about the social conditions for the appearance of technical developments as much as the problem of their impact in society and culture.

Considered from this broad perspective, the history of technology inevitably provokes disquietudes regarding the interpretation of its development through time: Is it possible to design a model capable of explaining technological changes and their impact in societies? Is there some pattern that has governed the development of technology in the course of history? Does it make sense to speak of a logic of technological development"?

In principle, it is tempting to apply to the realm of technology models of development that have been amply debated in relation to scientific development. In technics, as in science, there is a certain consensus about the progressive character of its development. Moreover, even if technological development is a long term process that goes back to the origins of the human species, from the Renaissance the relation between science and technics has so tightened that nowadays they constitute almost inseparable areas of human activity. As Ladriere points out, ancient technology "develops very slowly, on a basis that seems to have been essentially practical", while what is typical in modern technological development is that its evolution is increasingly more rapid and more systematic and more conscious due to "the intimate relation that has been established during that last two centuries between science and technology"[1]. Science (as much as technics) develops very slowly during the greater part of history, until it takes off at the end of the Renaissance and experiences an abrupt acceleration in the last two hundred years. One would expect, therefore, that the logics of development of science and technics be at least partially similar and that the understanding of the logic of scientific development would shed light on our understanding the nature of its twin sibling, technological development.

However, the nature of scientific development has been interpreted in very different and hardly mutually compatible ways. According to the exhaustive reconstruction carried out by Losee, two main theories of scientific progress have dominated the discussion in the philosophy of science during the last century. On the one hand, we have the theories of scientific progress as an incorporation. These theories draw out models of cumulative development according to which science gradually increases the reach of knowledge thanks to the successive contributions it receives along the way, in a dynamics that is similar to "the confluence of tributary currents that form a river". On the other hand, there are those theories of progress as a revolut*ionary change* . These theories draw out models of discontinuous development, according to which science develops thanks to successive episodes of rupture that introduce new paradigmatic forms of seeing the world, or, in other words, thanks to successive revolutions capable of provoking "changes that have an impact in subsequent scientific practice"[2].

These models, even if they seem to evoke an acute dichotomy between particular interpretations of the history of science, in fact correspond more generally to two possible ways to understand all sort of historical transformations. Faced with processes of change in prolonged periods, the interpreter can always ask himself if this or that development obeys continuous gradual modifications (such as the formation of a reef or the erosion of a mountain range) or sudden and turbulent changes tat only take place occasionally (such as the eruption of a volcano or the coastal devastation caused by a Tsunami). The concepts of evolution and revolution are thus available as useful tools in explaining comprehensive historical processes. When we apply these concepts to ask about the nature of

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[1] Ladriere, Jean, *El reto de la racionalidad*, Salamanca: Sígueme, 1977, pp. 49-50.

[2] Losee, John, *Theories of Scientific Progress*, New York/London: Routledge, 2004, pp. 11, 63.

technological development, the question is posed as follows: Is technics developed through a revolutionary or an evolutionary path? Does it progress through sudden discontinuous jumps or by slow gradual changes?

To explore this question, in the following section briefly we will briefly outline the revolutionary and evolutionary interpretations of the history of technology and see in what sense these positions are not mutually incompatible; in the second part, we will reconstruct the typology proposed by Serres in his effort to characterize technological development through a model that overcomes the dichotomy revolution / evolution; to finish, we will show how these different approaches to the history of technology can influence the formulation of theories of technological change.

1. Revolution and evolution in the history of technics

The origins of the history of technics as a subfield of historical research are very recent. While there were some isolated forays into the subject during the nineteenth century, only up to 1935 *"the Annales* of M. Bloch and L. Febvre, evidenced the great interest that should be paid to them by devoting an entire issue to the history of technics."[3] Around the same period, Lewis Mumford published his pioneering work *Technics and Civilization,* which makes an ambitious exercise of reconstruction and periodization of the techniques of the last thousand years. These milestones, despite their embryonic nature, are credited with having spurred the interest of researchers in the topic. Since then, the volume of academic output on the history of technology has continued to grow, to the point that the literature has become unmanageable. For this reason, in this section we will only present punctual formulations of the two interpretative orientations that we want to contrast.

The dominant interpretation of the history of technology, widely disseminated through encyclopedias and textbooks, often articulates its account of technological developments around three or four revolutionary phases separated by periods of more or less prolonged stability. In this respect, the term *technological revolutions* is used to refer to privileged moments in history, in which the technical capacity of humanity experiences crucial qualitative breakthroughs, which in turn trigger significant alterations in the course of civilization. According to this approach, the changes generated by a technological revolution lead

[3] Gille, Bertrand, *Introducción a la historia de las técnicas*, Barcelona: Crítica, 1999, p. 33.

mankind to a new level of progress associated with an overall improvement in the quality of life of people.

A classic version of this model is found in the work of V. Gordon Childe.[4] In his reconstruction of the origins of civilization, the author identifies two major technological revolutions on the border between prehistory and recorded history: the Neolithic revolution and the urban revolution. In the first, and as a consequence of the development of food production, human beings are freed from the hunter-gatherer status and make the transition from nomadic life to sedentary life. In the second, thanks to the development of the earliest forms of writing and recording, as well as the formation of cities, human beings take the step from prehistory to recorded history and provide a durable foundation for the process of civilization. Despite their differences, these two moments in the past have traits in common. On the one hand, it is about crucial links in the human effort to control and transform nature to suit their needs and desires, on the other, it is about developments that make possible a rapid growth of human population and induce a higher level of complexity in social institutions.

Gordon Childe, in his quest for an objective procedure for measuring progress, proposes a quantitative criterion by which a technological revolution is synonymous with progressive development provided that its net effect will result in a significant increase in population size.

The transition from the Paleolithic to the Neolithic was a step forward in the path of progress because the development of food production made it possible to sustain a population at least ten times larger than that characterized the nomadic groups of hunter-gatherers.

Similar statements, although based on very different numbers and proportions, apply also to cases of the urban revolution and, more recently, the industrial revolution, which can be considered successful to the extent that they "facilitated the survival and multiplication of the species ". This criterion of progress works, according to Gordon Childe, as a verifiable indicator that a technological revolution has taken place. For this author, a technological revolution is reflected "in a manner similar to that of the Industrial Revolution: by a change of direction, upwards, of the population curve of population"[5]

This criterion, influenced by the Malthusian theory of population, has the disadvantage of having been surpasses by history. Neither Malthus nor

[4] *Cf.* Gordon Childe, V., *Los orígenes de la civilización*, México: FCE, 1997.
[5] *Ibid.*, pp. 24-25.

Gordon Childe could foresee, in their time, the invention of contraceptive methods widely used today, such as the pill or the condom, and much less the cultural evolution that would change in the second half of the twentieth century the demographic trends in many countries.

For that reason, an approach based on considerations about the increased population size puts us in a bind when defining whether the recent information revolution qualifies as a technological revolution, because its development has been driven by countries in which the population size has entered or is about to enter a stationary, if not decreasing phase. Furthermore, modern contraceptive methods can be viewed as an indirect effect of the industrial revolution itself, the expansive wave of which continues to weigh powerfully in the dynamics of the contemporary world. Moreover, as Huxley's novel *Brave New World* already sensed it, the development of biotechnology opens the doors of a technological revolution that may lead to further dissemination of effective technics in the matter of population control.

There are variants of the revolutionary model that set a different criterion for marking the periods of the history of technics. One of the best known is that of Mumford, who concentrates on the resources, the materials and forms of power generation dominant in different periods of history.

Use has already enshrined, in the practice, the use of the names of raw materials to characterize specific stages of prehistory and history; the is why we speak of the Stone, Bronze, Iron, Coal or Silicon Age. In a similar vein, the author distinguishes three main phases in the history of technics: "Expressing ourselves in terms of energy and characteristic materials, the ecotechnic phase is a water and wood complex, the paleotechnic phase a coal and iron complex, the neotechnic phase a complex of electricity and alloy ... Every period of civilization bears within it the insignificant waste of past technologies and the important seed of new ones: but the heart of its development is within its own complex"[6] "6.

Thus formulated, the criterion is imprecise because it does not allow you to draw clear boundaries between one phase and another (historical data highlight many examples of overlap at different times), however, it underlines the fact that technological change does not consist only in the invention of new machines and tools, but also in how they are inserted like pieces in a complex operation involving the functioning of the various social subsystems. The idea of technical "complex" proposed by Mumford

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6 Mumford, Lewis, *Técnica y civilización*, Madrid: Alianza Editorial, 1998, p. 129.

helps to avoid the dangers of putting too much emphasis on technical innovation considered in isolation and forces us to think of how the innovations are articulated with the social system and the environment.

This type of reconstruction, in which the history of technology appears as a process marked by decisive changes with far-reaching social effects, remains fully valid today, whether it is considered that the alterations are due to specific inventions, to steps away from one material to another or changes in the forms of production and energy use.

The idea of technological revolution is often used to refer not only to massive transformations as those associated with the Neolithic revolution or the industrial revolution, but also to describe changes brought about by specific technological inventions in specific areas of human activity. We speak, thus, of the revolution unleashed by the steamboat navigation on navigational techniques, of the shock involved in the introduction of the wheel in the techniques of war, transport and communication, or the changes wrought by the printing press in the methods of recording, cultural reproduction and information transmission.

In fact, most of the works combine the periodization based on phases of revolutionary change with more or less detailed descriptions of the shocks --or, if preferred, of the small-scale revolutions-- triggered by specific technical developments.[7]

Thus, the history of technology usually takes the form of a story arranged in chronological order, in which the inventions appear one after another together with a description of the most notable social effects arising from their diffusion.

However, some authors have departed from this explanatory model. George Basalla, for example, suggests that, for purposes of writing the history of technics, it is more appropriate to appeal to the concept of evolution than to that of revolution.

According to Basalla, the ideas of "revolution" and "evolution" are metaphors (one from the realm of politics and the other from the realm of Biology) by which one can interpret the history of technology.[8] Basalla acknowledges the traditional dominance of the revolutionary metaphor, however, in his view, the evolutionary metaphor is more useful and convenient as descriptive tool. The evolutionary model resulting from this

[7] See also, for example, the cited work by Mumford, or also *A Short History of Technology*, by T.K. Derry y T. Williams.

[8] *Cf.* Basalla, George, *La evolución de la tecnología*, Barcelona: Crítica, 1991, pp. 14ss.

change in perspective stresses the continuity and progression of technological change.

To understand this shift, it is worth remembering that the interpretation of the biological world and the technical world have often lent one another their explanatory models. In the Renaissance it was customary to interpret life in mechanical terms. Rossi, among others, has shown how at that time the products of art and human invention, i.e., machines, served "as the model for conceiving and understanding nature." Not that art was in itself nature, but that nature is something like a product of art.

To understand the functioning of the human body they used the machine."[9]

Descartes in the *Treatise on Man,* likened human muscles and tendons to springs and the functioning of the body with the movements of a clock or a mill; Boyle, meanwhile, considered that the universe was "a great piece of clock-work ". However, due to the works of Darwin, the mechanical-technical interpretation of the world in biological terms became popular.

The Victorian writer Samuel Butler, in "The Book of the Machines," --published as part of his utopian satire *Erewhon or Over the Range--,* presented the idea according to which the machines of his day were just primitive links of an evolutionary chain that would produce in the future increasingly sophisticated types: "There is probably no known machine which is not a prototype of future mechanical life. Today's machines are for those to come what the first dinosaurs are to man. The largest of them certainly will decrease much of their current size.

Some of the lower vertebrates achieved a far greater bulk than their modern descendants have inherited, endowed in exchange with higher organisms; in the same way, a decrease in the size of machines has quite often followed a parallel march in their development and progress."[10]

In other passages of the story, Butler inverts Descartes' views and compares the performance of machines with that of living beings: "The steam machine absorbs food that it consumed by means of fire, just as man consumes its own; it keeps combustion going by means of air, just as man keeps its own; it has, just as man does, pulse and circulation."[11] The subsequent authors, following Butler, applied evolutionary theory to the history of technics, refining the use of these metaphors, to avoid forcing the

[9] Rossi, Paolo, *Los filósofos y las máquinas. 1400-1700*, Barcelona: Labor, 1966, pp. 133-134.

[10] Butler, Samuel, *Erewhon or over the Range*, London: Penguin, 1985, p. 202.

[11] *Ibid.*, p. 208.

analogy between the organic world and the artificial world. For example, it is obvious that technical devices are not perfected through natural selection processes, as in biological evolution.

According to the early proponents of technological evolution (authors like Pitt-Rivers, Gilfillan, Ogburn and others), improvement of machinery is due to an unconscious selection process conducted by humans. Every little improvement introduced by a craftsman into an artifact contributes to some extent to technical progress and to the diversification of all available devices.

Basalla incorporates these ideas and develops them in detail. His theory of technological evolution is based on four key concepts: diversity, continuity, novelty and selection.

According to Basalla, the artificial world contains much more *diversity* than was strictly necessary to meet basic human needs; that is a result of the *continuity* of technological evolution. However, the *novelty* is a integral part of the artificial world, to the extent that it requires a *selection* process in the selection of new devices for its reproduction and incorporation to the cluster of artificial things.[12] In his detailed analysis of these concepts, Basalla stresses the continuity of technological development.

Appealing to examples such as stone artifacts, the wheel, the printing press, steam engine, the bulb, the electric motor, the transistor and others, this author shows that every invention has a long preparation and, in many cases, a list of documentable antecedents and a long evolutionary history. When an invention is successful and spreads, its evolution is not for that reason detained, but rather it gives way to an ulterior process of refinements and improvements, and may even promote the emergence of new branches in history of the evolution of existing technology.

According Basalla, there are three sources that feed the thesis of the discontinuity of technological change: "the loss or concealment of crucial antecedents; the presentation of the inventor as a hero; and the confusion between technological change and socio-economic change."[13]

A technological development may seem revolutionary, either because its previous evolutionary genesis is not visible in the absence of a careful historical reconstruction, or because national or personal interests make the figure of inventors as isolated and genial cases, or else because the

[12] Basalla, George, *o.c.*, p. 40.

[13] *Ibid.*, p. 78.

inventions considered in themselves are confused with the social effects that subsequently arise.

According to this perspective, technological development evolves slowly and gradually, even though its social consequences may well be revolutionary: "Industrial change in the late eighteenth and early nineteenth centuries were really revolutionary in the way they affected the lives and fortunes of people in England. However, machines, and the steam engines that moved them were the result of evolutionary changes in technology ... The upheavals in the social and economic realm have been too often wrongly interpreted as revolutionary changes in technology. The implementation of the first industrial society in England was a change of such magnitude that it overtook the technological continuity on which it was based and helped to perpetuate the idea that technology advances by leaps from one great invention to another."[14]

The revolutionary impact of technological development does not therefore depend on the inventions themselves (always located in the middle of an evolutionary chain in which the differences with their ancestors and their descendants is one of degree), or the genius of their inventors (that owe more to tradition than they or their biographers are often willing to acknowledge), but on the use society makes of those inventions (which can cause widespread upheaval of traditional lifestyles). Therefore, insofar as the technique itself is concerned, we should not speak of technological revolutions, but of the evolution of technology. These developments, however, often cause sudden and unexpected social transformations. From this point of view, the use of words such as "industrial revolution" or "computer revolution" appears to be fully justified.

These explanations lead us to a picture of technological development that is far from being incompatible with the image that stems from the revolutionary model. One can even say that in a sense, the two images need each other. On one hand, in both the chronological order of appearance of technical development plays a central role, although in the evolutionary model each invention is determined structurally as a *member of a species,* so to speak, and no longer simply as a milestone in the history of civilization. On the other hand, the revolutionary model already implied in itself an evolutionary element, to the extent that the revolutions were milestones of a long-term civilizing process that went beyond them, turned them into links of a single chain and gave them meaning. Hence the question of the degree of progress associated with technological

[14] *Ibid.*, p. 82.

development is a concern common to both approaches. Strictly speaking, the history of technology is not just the artifacts themselves, but also their sociocultural impact.

A comprehensive reconstruction of the history of technological development has to do justice to both the gradual generation of devices and machines as to the discontinuities that can be generated in the field of social dynamics. Revolutionary and evolutionary models, far from being exclusive, are complementary.

We will presently examine a recent theoretical proposal that is relevant to clarify the nature of this complementarity.

2. The history of technics: an alternative model

If the history of technics has to do with artifacts, but also with institutions; with machines, but also with communities; with tools, but also with resources; with technological change but also with social change; an alternative model that seeks to account of its development has to offer a broad scope in which it cam accommodate the connections between these various factors.

As noted by Volti, "technological change has been a major force in shaping social roles and institutions, although their development has been the result of human actions that take place in a particular social environment."[15] The social organization impacts the development of the technics, and this, in turn, helps shape the former in a constant mutual feedback.

We should add to this the environmental factors, that have been, not in vain, a growing concern in recent decades and without whose help neither the societies nor the technics could have developed. The model proposed by Michel Serres to interpret the history of technology is situated in the broad context of this approach to the subject.

The first novelty introduced Serres is to articulate the history of technology not around a single thread running from the Paleolithic era to today, but around three different threads, three main streams of development that are not ordered chronologically as parts of a successive linkage, but run parallel throughout history, though their paths overlap and intersect again and again.

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[15] Volti, Rudy, "Reuniting History and Sociology through Research on Technological Change", in: *Bulletin of Science, Technology & Society*, XXIII, 6 (2003), p. 463.

In each of these currents, technological development evolves slowly, although its results generate revolutionary social transformations in very precise periods.

Each of the currents is characterized by Serres[16] according to a range of variables including the type of energy used, the typical forms of work, the dominant economic mode of production, the historical peak moments and, finally --what constitutes a second and interesting novelty--, certain mythological figures and certain symbols that serve as emblems associated with three types of technology.

The first current of technological development is presided by the figures of Atlas and Hercules.

These characters are defined above all by their strength, their ability to mobilize or support weights; they are heroes of mechanical strength, both static and dynamic. Their activity is built around stable, permanent, cold elements.

First is Atlas, whose task is to hold the sky on his broad shoulders (a comparable job to that of a caryatid or column of the Parthenon). The figure of Atlas evokes the monumental architecture characteristic of the great despotic empires of antiquity: the Egyptians, the Chinese, the Babylonians, the Aztecs, and the Incas.

The construction of colossal monuments --walls, temples, pyramids, ziggurats--, depends on the vertical arrangement of blocks of stone, rock, or marble. The result: stable, solid works that defy the passage of time.

Immediately following is Hercules, whose legendary labors constitute a display of physical strength as the ability to mobilize the elements. According to Serres, with Hercules it is not just a matter of holding the weights but of transporting, displacing them, "passing from the purely static work to the cinematic work, in movement, or the dynamics of a transformation: swimming so that the ship advances, cleaning the stables ... "[17] and so on. As the sweat brings out his body, Hercules rows, runs, moves rocks, channels the river waters, lifts or chases monsters, strikes them with his mace, presses them between his muscular arms.

In this first type of technology, rooted in mechanical force, we can group works as diverse as tilling the land, housing construction, navigation by oars or sails, the making of blankets and the construction of irrigation systems.

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[16] *Cf.* Serres, Michel, *Atlas*, Madrid: Cátedra, 1995, pp. 115ss.

[17] *Ibid.* p. 117.

Farmers, builders, architects, weavers, carvers and sailors are, according to an organic analogy used by Serres, the "skeleton" and the "muscles" of society, they mark the dominant type of technical activity in the early stages of development of civilization.

While such work has existed since ancient times and survived until today, its time of prevalence corresponds to the height of the empires, after the Neolithic revolution, contemporary to the urban revolution that remains thereafter, reaching the Middle Ages and the Renaissance.

The second current of technological development is dominated by the figures of Prometheus and Hephaestus. These characters are defined primarily by their ability to transform objects through the use of fire; they are heroes of the caloric force, allegories of thermodynamics. Their activity is built around warm, glowing, fiery elements, fluid by force of combustion. By the use of fire, Prometheus taught mankind how to cook their food, to warm their bodies battered by cold, to confront the wild beasts, to challenge the darkness of night. The Promethean fire like a torch that lights the path of progress, has been emblematic in Western art and literature of the process of civilization.

Hephaestus, in turn, softens the hardest metals in his forge and converts them into delicate filigree in gleaming weapons. His work anticipated the era industrial furnaces and engines. According to Serres, from the late eighteenth century "the burning transformation of things became the basis of the work, which fuses the ore into ingots and turns them, on the basis of industrial designs, into a thousand machines that cross the space loud and fast , leaving behind them a toxic trail"[18]

In this second type of technology, founded on the caloric force and chemical combustion, we can group such work as the cooking of food, the preparation of torches and candles, the forging of metals, steam navigation, the construction of vehicles, turbines and other machines driven by fossil fuels and so on.

Cooks, blacksmiths, drivers, builders, laborers and industrial workers are, according to the organic analogy used by Serres, "the metabolic system" of society, they mark the dominant type of technical activity since the industrial revolution. While the conquest of fire can be dated back more than a million years ago, its day of dominance corresponds to the heyday of industrial civilization, which began to take shape about 250 years ago.

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[18] *Ibid.*

The third current of technological development is governed by the figures of Hermes and the angels. These characters are defined primarily by their ability to record and convey data, they are champions of the electromagnetic forces, metaphors of electronics.

Their activity is organized around the volatile, the virtual, the ethereal, intangible messages, information processing. Hermes, messenger of the gods, inventor of the lyre, protector of commerce and guardian of travelers, with his winged sandals moves quietly and subtly, but with the speed of thought. His mission is to inform, to establish effective communication links between various points in space.

Angels, roaming figures, like Hermes, but much more numerous, connecting heaven and earth, bearers of good or bad news, translators that connect men with the gods, tireless travelers through networks and circuits (in this regard, it is worth remembering that the Greek word *angelos* means "messenger").

According to Serres, Hermes and the angels are the emblems of our own time. "Think, when going to work in the morning, the crowd passing through the streets: how few Prometheus and even fewer Hercules and Atlas, in comparison with so many Archangels, who set off to travel carrying messages! We live now in a great courier company."[19]

In this third type of technology, grounded in electricity and the processing and transmission of information, we can group such work as teaching, writing books, acting, design, music, financial transactions, communication, electronics and many others.

Messengers, systems engineers, bank clerks, politicians and diplomats, artists and writers, contractors, teachers, journalists and communicators, lawyers, a whole army of officials, advisers and white collar intermediaries (following the organic analogy used by Serres) the "nervous system" that defines the dominant type of technical activity nowadays.

There is no doubt that we human beings process information, data and symbols from ancient times, however, only until our own time, with globalization, information technology and biotechnological revolutions and the establishment of a knowledge society, this type of activity happens to occupy the foreground, displacing other traditional activities.

According to the model of Serres, the three major currents of technological development accompanying humans since prehistoric times, each requiring specific natural and human resources.

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19 *Ibid.*, p. 118.

While each current has followed its own line of gradual development, they have not reached the peak of their bloom at the same time, thus the history of technology can adopt, according to the viewpoint that it chooses either the appearance a line broken in stages of revolutionary progress, or else the appearance of a cumulative gently progressive slope. Serres's model offers an integrative framework in which these two traditional approaches complement each other.

In order to discern more clearly the strengths and the explanatory power of the model, it is worth examining carefully the following scheme in which we have summarized the proposal:

Technology type	*Peak phase*	*Characterization*
Atlas and Hercules: Mechanics	(Neolithic Revolution)	The solid, the permanent. Symbol: The land (the farmer) Organic analogy: The skeleton and muscles Verbs: To support, form, transform (in cold) Main economic activity: Agriculture
Prometheus and Hephaestus: Thermodynamics	(Industrial Revolution	The fiery, the warm. Fire (the blacksmith) Organic analogy: The metabolic system Verbs: Heat, transform (using heat) Main economic activity: industry
Hermes and the angels: Information theory	(Informatic Revolution)	The volatile, virtual, immaterial. Symbol: the air (the messenger) Organic analogy: The nervous system Verbs: Report, transmit, communicate, record Main economic activity: services

Read vertically, this table specifies the characteristics of the three major types of technology.

From this first viewpoint, it is obvious that mechanical technology was the first to thoroughly permeate and shape the functioning of societies, much later thermodynamics came to the fore; most recently it has been informatics.

However, the realization of the technological types in history is not diachronic but synchronic.

From this second point of view, it is necessary to read the table horizontally.

The three types do not appear one after another but are displayed ne beside the other since ancient times. Already 35,000 years ago humans were using bows, arrows and canoes (mechanical type), lit bonfires and torches (thermodynamic type), communicated and drew bison on the cave walls (informatic type).

From the Neolithic, agricultural production (mechanical type) comes to the fore, but this does not mean that no other technology continues their development, as evidenced by the invention of pottery kilns and metalworking (thermodynamic type) and the invention of the first writing systems (informatic type).

With the industrial revolution, the steam engine (thermodynamic type) displaced old processes of energy use, such as sailing. However, many aspects of navigation continued to depend on other technology types, for example, the supply of coal to the boilers involved the use of shovels on the part of stokers (mechanical type), while logging routes and determining the location of ships depended on the processing of data provided by the compass and the stopwatch (informatic type).

Today we witness an information revolution in which communications and services are coming to the fore without its causing that broad swaths of economic activity cease to have a thermodynamic or mechanical base: "Of course, now and always, the old tasks remain with enjambments and remnants: we will never be able to dispense with peasants or carvers, masons or tinkers; but although we remain archaic in two thirds of our conducts, some works, more than others, give an age its consistency and its unique colors: whereas in the past we were rather farmers, and not so long ago especially blacksmiths, we are now mostly messengers, though still reliant on the fields and the factory."[20]

Thus, it can be said to be the relationship between the types of technology and the predominance of one or another system that defines the technology of an age or a society. In this context it should be noted that human activities can radically alter their routines and procedures when their technological base changes. Let us consider an example.

Throughout most of history agriculture based on mechanics was the dominant economic activity (and still is in many Third World regions). Since the industrial revolution, agricultural methods suffered drastic transformations. With the advent of tractors and chemical fertilizers, came the era of agricultural production based on oil. Nowadays we see how agriculture is about to suffer a new shock, due to discoveries in the field of biotechnology. Currently, biotechnologists, by processing and manipulation of genetic information, are beginning to establish an information base for the production of food.

Accordingly, it is not just about highlighting the stages of technological dominance of one type over the other, it is also a matter of seeing how each new relation of forces introduces profound changes in the line of development of each of the technological types. These, far from being

20 *Ibid.*, p. 119.

impervious to each other, are constantly exposed to intersections and mutual influences.

Therefore, when studying the history of technology, we must pay attention to diachronic thread running from the past to the future, but also to the synchronous thread that links together technology types amongst themselves and with their social environmental surroundings.

Thus the Serres model not only clarifies the notion of technological system and provides a framework for interpreting the development and changes of that system over time, but also invites us to think the multiplicity of interactions between technological systems, social institutions and nature.

This is a systemic model, sensitive to complexity. Its application reveals that the contemporary technological system is more complex than any before, in a sense that exceeds the simple recognition of the breadth and diversity of the repertoire of available machines in everyday life.

The point is that we have inherited the cumulative effects of three different technological lines which have been maturing and enriching each other, especially in recent times. We know from experience that the diffusion rate and extent of the impact of new technologies has increased dramatically. Because of this and the rampant globalization process, the interactions between technology, society and environment have also become more intricate, and will be even more so in the near future. In this regard, it is worth remembering that the rate of technological development increases over time because it is an autocatalytic process.

Diamond, among others, has shown how, as the stock of technology and technical expertise of a community or a society grow, the rate of development of new technologies increases, either because "the advances depend on the previous domain of simpler problems" , or because "new technologies and materials make it possible in turn to generate other new technologies by recombination."[21]

These are not the only factors that affect the acceleration of the process, also changes in the relationship between science and technology have to do with it.

In Serres' model, the history of technology seems to be associated synchronously with the history of science, without denying, however, that this is a changing relationship along the diachronic axis. Thus, many mechanical technologies, daughters of long practice and learning processes

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21 Diamond, Jared, *Guns, Germs, and Steel. The Fates of Human Societies*, New York: W.W. Norton, 1997, p. 259.

by "trial and error ", predate scientific theorizing, while others, conversely, are their result. The same is true in the fields of thermodynamics and information theory.

The increasingly closer link between technics and science since the fourteenth century, amply documented by Rossi[22] has been in this sense another key ingredient to the acceleration of technological change. This acceleration has social, economic and environmental consequences which confront us today.

The latest phases in the history of technology have also been those of faster propagation and more explosive effect.

Serres's model shows that the transition from the dominance of the solid to that of the igneous, and from this to that of the volatile, is accompanied by an exponential acceleration of the pace of change.

At the level of the economy, with the advance of capitalism we have moved from the primacy of the primary sector to tertiary sector of the economy in just two hundred years. On the environmental level, the process of pollution unleashed by the industrial revolution has begun to make its effects felt globally.

Although the numbers and rates of these and other changes may vary greatly from one continent to another and from one region to another depending upon the specific geographical and historical specifics, the fact is that we have reached a stage of the process of civilization in which the main task is to learn to live in a situation of "permanent change".

3. Conclusions

Since the history of technology involves both the invention of devices and their integration in the social and natural systems, the dilemma posed at the beginning of the article ("is the technique developed through the revolutionary or the evolutionary path?) shows itself ultimately as a false dilemma: revolution and evolution are elements of the history of technology, and their combination in a unified model strengthens our ability to understand its development.

The changing contemporary "technosphere" is the result of a prolonged history that has involved both the evolutionary changes in technology and the revolutionary changes in society, and therefore, in the technological development itself, to the extent that this is itself a social process.

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[22] *Cf.* Rossi, Paolo, *o.c.*

Therefore, it is not surprising that the formulation of theories of technological change has been a central topic for the philosophy of technology in the last 25 years. Among the researchers working in this field there is a growing awareness of the desirability of using an interdisciplinary approach to capture the complexity of today's technological system. In this respect, the study of a model that applies a diachronic and synchronic axis to describe the history of technology has given us some important clues.

The first is that technological systems are never autonomous with respect to their social conditioning. To hold, move, heat, transmit, communicate are actions that take place within complex institutional frameworks.

The machines would be inconceivable without the social framework from which they derive their meaning: "An agencing is never technological, it is just the opposite. The tools always presuppose a machine, and the machine, before being technical, is always a social machine. There is always a social machine that selects or assigns the technical elements used. A tool will remain marginal or little used until there is the social machine or collective agency able to include it in their 'phylum'."[23]

Increasingly the theories of technological change are focusing their efforts on understanding the coupling of technical machines with the social megamachines.

Pioneering authors like Marx, Gordon Childe or Mumford were already aware of this need. If such awareness has increased in recent years, this is due largely to the inadequacy of linear models of explanation to which these same authors (and others) appealed.

The articulation of a cross-section analysis with another multilinear analysis and of a diachronic perspective with another synchronous perspective (as we have seen in Serres' proposal) show that technological systems function as complex networks, which include elements from different types technology and are articulated with social and natural environments with which they have multiple feedback relationships. Contemporary research has not been immune to this new approach.

Langdon Winner, for example, argues that "technologies are forms of life"[24] and that the history of technics is the history of the ways technology has been lived, rather than merely used. In a similar vein, Diamond shows how differences and asymmetries of technological development in different

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[23] Deleuze, Gilles & Claire Parnet, *Diálogos*, Valencia: Pre-Textos, 1997, p. 80.

[24] Cited by Misa, Thomas, "Theories of Technological Change: Parameters and Purposes", in: *Science, Technology & Human Values*, XVII, 1 (1992), p. 6.

continents throughout history obey geographical and environmental factors that have shaped the development of civilizations for thousands of years.

This author states further that we should not study the development of technology abstracting it from the social conditionings that bear upon it; on this particular point he warns, for example, that "once an inventor has found a use for a new technology, the next step is to persuade society to adopt it. Having a larger, faster or more powerful device to do something does not guarantee its acceptance."[25]

Bruun and Hukkinen, meanwhile, have sought to develop an integrated model for the study of technological change[26], in which they incorporate the contributions of three distinct theoretical frameworks: evolutionary economics (which stresses the links between technological change and economic dynamics), the social constructionism of technology (which argues that technological change depends primarily on social processes) and the theory of "actor-networks" (according to which technological artifacts participate in the construction of a network of relationships that goes beyond the explicit aims of the actors who use them).

A second clue that follows Serres' model regards the determination of the causes of technological change and its subsequent effects.

As technological systems obey a dynamic in which the diachronic development of the technological types is combined with their synchronous links and their connections with the social machines and their environmental settings, their causation is never linear and univocal, but complex and multicausal.

Consequently, the task of the historian of technology (and also the theorist of technological change) involves two complementary facets. On the one hand, it must establish as precisely as possible the background situation on which the causes that have the effect of technological development intervene; on the other, it must take into account the changes in the relations between forces that technological development itself produces when sprouting in a complex field of emergence which lead to the formation of loops that feed back into the process.

The genesis of technological change requires, so to speak, a "mapping". We must explore the facts insofar as they are connected to a

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[25] Diamond, Jared, *o.c.*, p. 247.

[26] *Cf.* Bruun, Henrik y Janne Hukkinen, "Crossing Boudaries: An Integrative Framework for Studying Technological Change", in: *Social Studies of Science*, XXXIII, 1 (2003), pp. 95-116.

surface, to a complex scheme of points and vectors. One of the merits of Serres model is that, rather than telling a story, it sketches a picture, drafts a map by which we can orient ourselves.

This change of perspective is especially relevant at the time of calculating the likely evolution of the technological systems and social machines to which they are associated.

On this point, the proposal in which Scherer extrapolates into the future the potential of technological change to modify the emotions and behavior of individuals is instructive.

While the author focuses on developments related to the third technological type (information technology), his effort is revealing in that the proposed exercise of extrapolation is based on a systemic approach to the problem.

Based on "the generally accepted accelerated social change today," Scherer considers it legitimate to "expect more dizzying changes in emotional processes today than at any other time in history,"[27]; at once, he tests this expectation in terms of four points: "(1) the effect of social change on those emotions that are closely tied to set values, standards, goals and ideals such as shame, guilt, contempt or indignation, (2) the effects of the use of emotion by the mass media in the emotional experiences and socialization of the emotions, (3) the impact of information technology on emotional expression and regulation, (4) the possibility of producing artificial emotions in autonomous agents—robots—"[28]

The mere listing of these tasks reveals the difficulty of calculating the reach that these dynamics can have. However, even despite the inevitable speculative component implies that this initiative involves (and which Scherer recognizes), the truth is that the calculation of the effects that can induce current technological changes is a crucial and urgent task. Of particular importance here is the transition from predominantly industrial civilization to informatic civilization.

As shown in the model of Serres, one of the main effects of the industrial revolution consists in multiplying the capacity of humans to contaminate their environment through the use of thermodynamics-based technologies. Technologies based on information theory seem, by contrast, cleaner and more hygienic; however, biotechnological manipulation in turn

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[27] Scherer, Klaus, “Emotional Experience Is Subject to Social and Technological Change: Extrapolating to the Future”, in: *Social Science Information*, XL, 1 (2001), p. 126.

[28] *Ibid.*, p. 125.

has an enormous potential to introduce substantial alterations and dysfunctions in ecosystems.

Faced with the current problems of environmental degradation and the challenges posed by the globalization process, prospective work such as Scherer's are becoming increasingly important. We definitely need to know more about the impact that technological manipulation has on society, on nature and on ourselves.

Clearly, the more we know about it, the better equipped we are to make intelligent decisions regarding the use of resources, the production of wealth, social organization and the resolution of global problems. Science and technology can be our best allies in these tasks, provided that we avoid the risks associated with their use. In this sense, the systemic study of the history of technology helps us refine the analysis capability we require to guide us in the difficult crossroads through which civilization is moving.

(Translated from Spanish by Victor J. Krebs)