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Physics, mind, society: back and forth

A paper in honor of Professor George Feher at the occasion of his 80th birthday

Ladislav Kováč

Department of Biochemistry, Comenius University, 842 15 Bratislava, Slovakia

Email: kovacl@fns.uniba.sk

Running title: Physics, mind, society

Address for correspondence:

Ladislav Kováč

Department of Biochemistry

Comenius University

Mlynská dolina

842 15 Bratislava

Slovakia

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Abstract

The life course of the physicist and biologist George Feher may be seen as an epitome of science of the second half of the 20th century and the beginning of the 21st century. Feher, a native of Slovakia, barely escaped Nazism and communism and became a scientist in the USA. The Nazi concentration camps and the communist gulags have become a symbol of the 20th century. This symbol stands here to pose a question: How the two totalitarian systems, fraught with irrationality, may have arisen and thrived in parallel with an unprecedented expansion of science, the paragon of rationalism? The question has become even more urgent in the 21st century. The Ground Zero, an empty spot left after the collapse of the twin towers of the World Trade centre on 11 September 2001, has become the symbol of the entrance of humankind into the new millennium. We can do much, but we understand too little about who we are and what we are doing – this is a message that the two symbols convey about the precarious stage of our evolution. The second message concerns the role of artifacts, specifically scientific instruments, in the advancement of science. Human cultural evolution has been steadily progressing, in a form of a ratchet, only because artifacts have been continually evolving. Contrary to the common Popperian wisdom, the demarcation in science may not consist in the amenability to theoretical falsification, but rather in the amenability to instrumental grasping. Scientific instruments have empowered humans for impressive feats of manipulation with Nature and themselves. Knowledge arising in the course of autonomous evolution of artifacts may surpass the horizon of human understanding and grasping. New knowledge may still be power, but no longer the power of humans. We may need a revision of some fundamental ideas of European thought. Our understanding of the human mind may entirely reshape our comprehension of the nature of physical knowledge, and vice versa.

„We have inherited from our forefathers the keen longing for unified, all-embracing knowledge. ... ...but, on the other hand, it has become next to impossible for a single mind fully to command more than a small specialized portion of it. I can see no other escape from the dilemma (lest our true aim be lost for ever) than that some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them – and the risk of making fool of ourselves." *Erwin Schrödinger [1]*

This is a unique period of human history. We have entered the century in which a major transition in the evolution of life on Earth is going to take place. The Singularity is near [2, 3]. In this ultimate phase of human evolution, both the density of events and the complexity of processes are continually increasing. One needs some orientation points, identification signs, beacons in order not to be lost in the deluge. The biophysicist George Feher may be such a beacon: his life course, both personal and scientific, may be seen as an epitome of the history of the second half of the 20th century and the beginning of the 21st century. This history is deeply rooted in, and fatally constrained by, human biology. The implications of this biological confinement are described in this paper. Feher's life and work, masterly presented in his personal overview [4], stands as a permanent background in this essay.

1. Ground Zero: the symbol of the entrance of humankind into the 21st century

In the attack on the United States on 11 September 2001 one of the most remarkable products of modern technology, the jet plane, hijacked by the terrorists, was used in the assault in service of religious fanaticism. The use of rational means for irrational aims – this is the message of the collapse of the twin towers of New York City's World Trade Center. It has been said that, by conveying this message, the spot left after the collapse, dubbed the Ground Zero, may have established itself as a symbol of the entrance of humankind into the 21st century.

The term Ground Zero may be taken not only literally but metaphorically. As an expression of the paradoxical situation of the contemporary humanity: we can do much, but we understand too little about who we are and what we are doing. Our capacity to grasp the world – in the literal meaning of the word: to grip, to mould, to manipulate – by far exceeds our capacity of understanding it: of perceiving meaning of things and events in their genuine contexts. This discrepancy will recur in this paper in relation to different topics. We know much of the inanimate world and of life at the level of molecules, and have a marvelous command over it, due to the advancement of natural sciences. However, our knowledge of the forces that direct human individual behavior and social dynamics is meager. Close to zero. The Ground Zero may be conceived as an appeal to annul most of the past explanations and to invest the bulk of our resources, both material and spiritual, into the search for a new, more appropriate, understanding.

Has this been done in the five years that elapsed since the events of 11 September, 2001? Already in 2003, an empirical analysis of data about the reaction to the events of both political and scientific establishments not only in the U.S., but worldwide, indicated no major change in traditional thinking [5]. As has been pointed out, "science should play a major role in understanding and suppression of human propensity to irrational thought and action". It has

been concluded that "science may have not met this expectation. A change in priorities of science seems desirable. The comprehension of the nature of individual and social mythophilia and the establishment of a science of values (axiology) may have become a most urgent task."

Not by chance the emphasis has been placed on human mythophilia. It is one of the most prominent species-specific characteristics of humans as a biological species. It expresses the need, enforced by the construction of the human neural system, to have a total, complete explanation of all events, the explanation in terms of intentions and purposes. Jacques Monod [6] called this manner of explanation animism. Part of mythophilia is the conviction that an individual or a group to which the individual belongs disposes of a full and incontestable Truth about the world. Full and incontestable, because it has been revealed. The Truth has been deposited in the Holy Scripture. One of the major plights of the contemporary humankind is caused by the fact that there are at least three Holy Books pretending to contain the revealed, and hence unquestionable, Truth: Judaic Torah, Christian Bible, and Moslem Koran. But already from time immemorial human groups fought with one another about which of the competing, and mostly contradictory, truths is the right and exclusively valid one. The matter is that in the 21st century groups of mythophilic animals no longer battle with bows and stone axes but with terrific devices of modern technology.

In his autobiographic sketch George Feher vividly depicts the troubles he had in 1944 as an applicant for a technical college: he failed his exam because of his poor knowledge of the revealed truth, deposited in one of the versions of the Holy Book. It is one of the most amazing symptoms of the ultimate phase that the Earth is inhabited by more than 6 billion members of a biological species that called itself proudly *Homo sapiens,* of which almost everybody, with negligible exceptions, is convinced that that there is only a single truth, indubitable, and it is the truth he/she possesses. The designation *Homo mythophilus* may appear to fit better this prominent feature of the species.

The adoption of the principle that no truth has been revealed to humanity is a precondition of any meaningful communication among human individuals or groups. There was no Being who dictated to obedient scribes the full truth about the world. Slowly, groping and fumbling, by trial and failure, are we reducing our ignorance. In fact, there is only by these slight, but permanently accumulating, pieces of knowledge that a Being, immanent to Nature, is gradually emerging. A Being that was absent at the beginning, and once, in the infinity of time, might become omniscient and omnipotent: human knowledge. What in between? It would be wise to strictly observe the principle of minimal prejudice: we should not claim that we know more than we know. The principle has been anticipated by many philosophers and scientists in such ideas as Occam's razor, economy of thought, parsimony. It may be called Jaynes' principle, according to the physicist who first gave it a precise mathematical formulation [7]. According to Edwin T. Jaynes, if one has an incomplete knowledge of the subject, the minimally prejudiced assignment of probabilities is that which maximizes Shannon's entropy, subject to the given information.

The principle of minimal prejudice has been observed by scientists – in their research work, but less or not at all in their everyday life. But even if the number of scientists on Earth amounted to one hundred million it still would represent but 1.6 per cent of the human population: at least 98.4 per cent of humans would keep living and acting convinced that they do understand the world fully and reliably. This phenomenon has been called the Great Disparity. The masses enjoy artifacts of modern technology and, at the same time, adhere to traditional myths, quite often contradictory to the ideas from which the artifacts originated. Table I depicts the precarious state of humankind in the first decade of the 21st century.

Table 1. The state of humankind in the first decade of the 21st century

Denotation	Description
Ground Zero	Disproportion between a spectacular progress of natural sciences (and corresponding performance of technology, economy and entertainment industry) and lagging behind of cultural (human and social) sciences
Great Disparity	Disproportion between people ready to observe the principle of minimal prejudice and the rest of the mythophilic animals sticking to disparate versions of the Revealed Truth
Singularity	The imminence of technological, and possibly also scientific and economic singularity, a point where the value of an otherwise finite and continuous function becomes infinite in a finite time

2. The heritage from the 20th century: the Tremendum and the need of its naturalization

It has been said often since 11 September 2001 that, on that date, the world we knew before ended. The American Baruch Myers, who is serving as a Rabbi of the Jewish community in Bratislava, Slovakia (incidentally, the birth-place of George Feher), commented on such views [8]: If our familiar world ended, it did not end on 11 September 2001. It ended on 11 May 1944. On that day, two of the four gas chambers in the concentration camp of Auschwitz were completed and started to operate. Five thousand Jews were murdered – more humans than perished during the collapse of the New York City's towers. During the next 44 days killing by gas went on day by day and in every single day ten thousand people died. It has been estimated that as much as 6 million Jews may have been killed by the Nazis.

This phenomenon of mass killing, called the Holocaust or Shoa, placed philosophy and theology before novel questions [9]. Traditional theodicy, an attempt to explain why omnipotent, omniscient and omnibenevolent God allows Evil in the world, turned to be inapplicable in this case: according to some thinkers, such explications of the enormous destruction and injustice would mean to scoff at the victims. Attempts appeared to exculpate God by admitting that He is not omnipotent and in face of excesses of human free will may be powerless. Others pondered on an instance of the temporary "eclipse of God": there are times when God is inexplicably absent from history. According to Richard L. Rubenstein [10], the only plausible explication of the Holocaust is the avowal that God is dead and the recognition that all existence is ultimately meaningless. If we want to find a meaning in the world we have to create it ourselves.

To express the historical uniqueness of the phenomenon of the Holocaust Arthur A. Cohen [11] introduced the term The Tremendum. As he put it, "thinking and the death camps

are opposed. The death camps are unthinkable, but not unfelt". Rudolph J. Rummel [12] estimated that the total number of victims of Nazism were 20.9 million. However appalling the latter figure is, it is but a fifth of the number of people that perished under Communism [13], the second totalitarian system. Justice requires to enlarge the term The Tremendum to the victims of Communism as well and to make of their respective idiosyncratic monstrosities, the Nazi concentration camps and the communist gulags, two symbols of the 20th century. Both Nazism and Communism have been considered by many commentators as secular religions. The French historian François Furet called them a "dual religion in the world without religion" [14] and the British historian Eric Hobsbawm spoke of the great wars of the 20th century as of the "(secularized) religious wars" [15]. This brings us back to the theme already sketched out: The weight of human mythophilia, which encompasses a religious component, in shaping social events, including violent conflicts, seems to be heavy and should never be overlooked.

In the absolute figures of human victims the 20th century was the most murderous century of the entire human history. However much it eased life by providing material wealth and entertainment to masses of people, it also brought forth immeasurably much human suffering. But Nazism was not a break in history, as Rabbi Myers may see it, and neither was Communism. They do not stand out of the equivocal advancement of the human species, stretched over centuries of cultural evolution. Definitely, they brought two novelties: the horrid death toll of millions of human victims; and the totalitarian rule. It was new technology that provided tools for both totalitarism and mass killing. Science, by intermediary of technoscience and technology, was eventually the main factor that made possible the era of totalitarism in the 20th century.

Here we are: the century of mass killing; but also the century of science, as the common saying has it. The Tremendum and its symbols pose a nagging question: How the two totalitarian systems, fraught with irrationality, may have arisen and thrived in the 20th century in parallel with an unprecedented expansion of science, the paragon of rationalism? This is not a question of theodicy. Let us called it the "question of logodicy". The puzzle of the Tremendum should be dethronized, "detheologized", naturalized. More than that: it should be transformed from a subject of philosophical reflection to a subject of scientific research – to phrase it in the form of scientific hypotheses that can be subjected to empirical testing.

As George Feher related in his personal account, he escaped the Nazis in 1941. Indeed, in a very last moment in his native country: he might have become one of the victims. Had he remained at his birth-place and had a chance to survive the Holocaust, he would have been confronted for 40 years with the freaks of the other totalitarian system, Communism. Instead, he became a scientist in the democratic United States. Graduated in electrical engineering, he worked for 20 years in physics, using mainly magnetic resonance as an experimental approach. In 1968 he switched to biology. The possibility to apply the techniques of magnetic resonance was one of the reasons why he decided to take up a study of the primary processes in bacterial photosyntesis. In fact, however, as he implied in his essay, his transition from physics to biology may have been conditioned by the lasting influence of a little book, written in 1944 by the physicist Erwin Schrödinger "What is life", which he had read as a youngster in his formative years [1]. Incidentally, a number of other prominent physicists equally opted for biology under the life-long imprint of Schrödinger. Was it not, after all, an unconscious attempt of the most brilliant human brains to approach the question of logodicy, posed and left unanswered by the Tremendum?

3. Naturalization downwards: from human experience down to molecules

In parallel with young George Feher, only 70 kilometers west of Feher's birthplace, in the city of Vienna, another young man, Eric Kandel, had his own experience with Nazism [16]. He escaped Nazism in 1939, two years earlier than George Feher, and later also became a scientist in the U. S. In the streets of Vienna, Kandel was a witness of orgies of people obsessed with mythophilic Nazi enthusiasm combined with racial contempt and hate. He asked a question that has remained his life companion ever since: "How are we to understand the sudden release of such great viciousness in so many people? How could a highly educated and cultured society that at one historical moment nourished the music of Haydn, Mozart, and Beethoven, in the next historical moment sink into barbarism?" Upon emigrating to the U. S., he decided to find an answer by studying European history and literature. The clarification of the nature of Tremendum might be, at the same time, the clarification of human nature. Later, he switched to the study of medicine to become a psychiatrist and psychoanalyst. The search for answer got a simpler and more concrete form: to try to explain the fact of the Tremendum from individual human psychology. He thought that psychoanalysis was "perhaps the only approach to understanding the mind, including the irrational nature of motivation and unconscious and conscious memory."

But how to do it otherwise if not by contemplating, speculating, by permutation of the ideas on human behavior in which philosophers have been indulging for centuries? It turned out that the problem must still be more simplified: to conceive human behavior as the problem of the human mind and the problem of the mind as the problem of the brain.

But how to study the brain, possibly the most complicated physical and chemical system on Earth? What kind of hypotheses to set, what kind of methods to use for testing them? After some work on the mammalian brain, Kandel decided to take a radically reductionist approach: to study a nervous system much simpler than is the human nervous system. He settled in 1962 on the giant marine snail *Aplysia californica*. It comprises only 20 thousand neurons, but very large, so that they can be easily manipulated electrophysiologically, and also dissected out for biochemical and molecular biological studies. His research of *Aplysia*, in particular studies on learning and memory formation, was so successful that he was awarded the Nobel Prize in 2000. In the meantime, research techniques evolved to such an extent that he could retake research on the mammalian brain. He eventually founded a biotech company Memory Pharmaceuticals, which arose from his laboratory research. The company is now at the forefront of an intense technoscientific and commercial race to devise the first effective memory enhancing drugs. In the magazine Forbes Robert Langreth reported that "scientists of Memory Pharmaceuticals are tantalizingly close to creating a kind of Viagra for the brain: a chemical that reinvigorates an organ that has faded with age" [17].

Life and work of Eric Kandel, no less than those of George Feher, may be seen as a paradigm of the state and evolution of the contemporary science. Had Eric Kandel devoted all his life to studies of history, literature or psychiatry, he would have definitely not earned the Nobel Prize. He may have published a number of brilliant essays on human nature, on the destructive force of human mythophilia, on prospects of humankind. Just as did so many historians, literati, philosophers for centuries. The readers may have drawn aesthetic delight from his writings, and Kandel may have contributed to their peace of mind. But his work would have had hardly any effect on individual behavior or on the course of history. His speculations on the Tremendum would have complemented thousands of similar reflections. The impact of his studies on *Aplysia* seems to be incomparably larger. Obviously, the knowledge of the molecular mechanisms of memory in the marine invertebrate is far away from our understanding of the phenomenon of the Tremendum; still, it may have brought us a bit closer to it. But much more important is the fact that the studies on *Aplysia* and their extension on mice and soon on humans can already now be exploited for controlling human behavior. From identification of genes participating in memory formation and from drugs

affecting retention or selective erasure of memories the way towards other genes and drugs is straightforward. Towards genes and drugs determining and controlling human aggressiveness, empathy, altruistic behavior, love and hate. And even mythophilia – the human feature that is one of the two recurrent themes of this essay.

This is where the second recurrent theme reappears. We will be able to grasp the pieces of the framework that constitutes our life before we understand the framework itself: to intervene, to change them, to copy them, to fabricate their synthetic imitations. As Nicholas Wade commented, "probably well before society is ready to assess the full implications, biologists believe they now stand on the threshold of being able to change fundamental aspects of the brain's architecture" [18]. He cited Eric Kandel: "Our understanding of memory processes is quite shallow – this is the beginning of the beginning. What the bad consequences or limitations are we don't really understand." In other words, we do not understand, but we already have, or will soon have, effective technologies. This may apply to all levels of human knowledge, from atoms to society. Here is an example from a completely different branch of science, from quantum physics. This is the appraisal by the physicist Anton Zeilinger [19]: "The philosophical conundrum alluded to by Schrödinger when he coined the notion of entanglement is still not sufficiently resolved, but investigation of these fundamental issues are already giving birth to a new technology."

Yet, who is going to take decisions on the application of new technologies, who is going to exploit them? Those six billion mythophilic animals of which everyone sticks to his/her exclusive truth, on which he/she bases behavior and action? Or only those 1.6 per cent of humans who are ready to admit temporariness and limitations of their knowledge; if so, who would empower them? But there is also a third possibility: no one can take any decision and affect anything, since the power, which already rules and acts, is the autonomous dynamics of processes that escape human grasping, and thus are blindly running out of human control.

4. *Homo mythophilus* is also *Homo artefaciens*

Science, a dominating and self-evident phenomenon of our time, has a remarkable origin. The idea that the world can be subjected to rational analysis, that the reason of individual human beings can, by means of logical inference, achieve an extensive and reliable knowledge of the world, may have appeared in human history just once. Or, at least, only a single time did it take up and persist in a human group: in the ancient Greece 25 centuries ago. The singularity of its occurrence demonstrates the formidable strength of human mythophilia and its resistance to change. Until then, all human cultures perfectly fitted the mythophilic nature of the human animal living in groups. It has been asserted that "after the discovery of fire this has been probably the second greatest discovery of mankind" [20]. Still, additional twenty centuries of an incubation period had to pass, in which the Greek thought was intermixing and fusing with the intellectual heritage of Judaism and Christianity, before Galileo Galilei introduced experiments into scientific endeavor and in this way launched a rapid expansion of modern science.

The achievements of science reinforced in the handful of those people in society who strive for rational explanation of events a belief in the unlimited potency of the individual human reason. It may have reached its peak in the Enlightenment of Continental Europe in the 18th century. It continues to thrive unabated up to our time. Equating human consciousness with thinking and reasoning is still one of the dominant paradigms in cognitive sciences.

Rationalism commonly serves as a ground of theories explaining the dynamics of scientific research. Among them, Karl Popper's conception of critical rationalism may have a dominating position [21]. Although Popper always insisted that he was interested in the

logic and not psychology of science, in his conceptions the actors of science are in essence rational agents who create by themselves or adopt from others scientific hypotheses and then attempt to refute them, falsify, by rational arguments. The hypotheses themselves need not have a rational origin or justification. A hypothesis should stand at the beginning of all research, both theoretical and experimental, even if not conceptualized (concepts are not important for Popper). The logic of incessant creation and successive replacement of hypotheses and theories determines the direction of science. The criterion of demarcation holds: a hypothesis or a theory is scientific only in case if it is falsifiable.

One of the conclusions that can be drawn from the experience of both Nazism and Communism is indeed a Popperian one, but, at the same time, it gives reason for questioning critical rationalism: the hypotheses of the classical European rationalism about the unlimited potency of the human reason have been falsified [22]. Humans are much less rational and intelligent beings than it has been assumed by European rationalists, from Aristotle through Descartes, the enlighteners of the 18th century up to the neoenlighteners of the 20th and 21st centuries, who believe in the unrestricted human perfectibility. This conclusion should be brought to its final and inevitable closure: science itself is not as rational as Karl Popper pictured it in his concept of critical rationalism.

All living beings are essentially "fanaticists". Simple biological species, with no ability to learn, are "absolute fanaticists": to frame it in the Popperian terms, if we take a mutation in bacterium for a modified hypothesis about the environment we can say that the mutant would sacrifice its life to prove its fidelity to the hypothesis. As aptly put by Popper, humans, contrary to simple organisms, do not need to die for their hypotheses. But human beings, including scientists, are far from being Popperian rationalists, eager to expose their own hypotheses for testing and ready to replace them by new ones. One of the most imaginative world biologists Susumu Ohno wrote already three decades ago that "man's intelligence in the genetic sense might be quite meager, not vastly different from that of the chimpanzee" [23]. As he prophetically surmised, "aware of the genetic near identity of man and the chimpanzee, his closest living relative, one can similarly make an convincing argument that attributes the differences between human intelligence and that of the chimpanzee to species-specific differences at one or two gene loci". And he added: "I would rather think that inner conflicts created by contradictory demands of individual genes are inherent in the genetic constitution of higher organisms. Man as a species is a study of contradictions..."

If the biological difference between humans and other animals is so slight how to explain the unique accomplishment of the human species, the magnificent edifice of civilization? All things and beings around us, which belong to the inanimate world or which are alive and have been produced in biological evolution by natural selection, can be labeled as naturefacts. But we are now mostly surrounded by completely different kinds of things, by artifacts. Artifacts are the specific stuff which civilization is made of. The human animal is also just a naturefact. The characteristics that have been often considered as specific to humans, such as bipedality, specialization of the forelimb to function as the hand, the large brain with extended cortex, the ability of spoken language, the ability to make tools, are also nothing more but naturefacts. Accordingly, the abilities of humans to adjust objects of the world for their own purposes, to modify them by the activities of their hands, the capacity of artefaction, even the capacity of creative work, however specific they may be to our species, are part of human nature.

What is no longer part of nature, however, are products of these capacities, the artifacts. It is by the products of artefaction that the human species surpasses nature and becomes a being *sui generis*. Not only the species *Homo mythophilus*, but also *Homo artefaciens*. By artifacts, humans transcend their biological immanence. It has been pointed out that the beginning of artefaction in the human evolutionary history marks the beginning of cultural

evolution [3]. The fact that cultural evolution has been a cumulative process is solely due to artefaction: a new material artifact is linked up with the preceding one, as its improvement, or as an innovation. Not only material products of craftwork, but social institutions are also sort of artifacts. Accordingly, science itself, the essential part of contemporary culture, is a huge artifact.

The evolutionary advancement of artifacts has been the main driving force of the steady progression of civilization. Science is generating, and in turns dependent upon, a specific category of material artifacts, scientific instruments. From the time of Galileo's inclined plane up to computers, particle colliders and DNA microchips, there have been scientific instruments that circumscribe the epistemic horizon of scientific inquiry, delimitating the nature of questions that can be posed meaningfully by science. In fact, the stories of Feher's work on photosynthesis and of Kandel's work in neurobiology provide a most convincing evidence of it. Nowadays, new instruments generate large quantities of novel data, but also, at the same time, define and demarcate research problems. Demarcation in science does not consist in the possibility of theoretical falsification, but in the possibility of instrumental grasping. There is a recursive feedback between scientific instruments and evolving research, a tight coupling between the character of the instruments and the character of scientific hypotheses [24]. There are the available research techniques that are promoting imaginative speculations to the status of scientific hypotheses.

Although the lagging of cultural (i.e. human and social) sciences behind natural sciences may have several causes, there is no doubt that one of them is the fact that cultural sciences lack appropriate instruments that would allow measurements and organized experiments. Popper's mode of critical falsification of theoretical hypotheses has not sufficed to spur cumulative progression of cultural sciences: for two and half thousand years, since the birth of science in the ancient Greece, cultural sciences keep turning in vicious circles of recurrent speculations. Natural sciences have long abandoned the concepts that Aristotle had used to explain the physical world, but cultural sciences continue to use his concepts in their interpretation of humans and society. Virtually the entire progress of cultural sciences up to now seems to consist in concrete descriptions of those new social changes that have been brought about by the progress of natural sciences [25]. But the large majority of these descriptions are based on those conceptions of humans and society that have survived unchanged since their invention by Plato, Aristotle and their contemporaries.

Karl Popper recognized the importance of artifacts in human evolution. He considered them to be part of his World 3. He said in his 1965 Arthur Holly Compton Memorial Lecture "Of clouds and clocks" [26]: "Human evolution proceeds, largely, by developing new organs outside our bodies or persons: ´exosomatically´, call it, or ´extra-personally´. These new organs are tools, or weapons, or machines, or houses." But, as Paul Levinson observed [27], "The problem with Popper's model is that its World 3 is drawn in terms too primarily **ideational**: the fundamental criterion for World 3 citizenship is being a humanly produced idea, with the material expression of ideas awarded a second-class or derivative status."

When Popper first published his theory of science in Vienna in 1935, he gave to his book the title "The logic of scientific discovery" [28]. The intellectual atmosphere in Vienna of his time may have indeed abounded in competing hypotheses and theories, and intellectuals, including scientists, may have made the best of their life by taking part in arduous critical discussions. Popper himself never worked in a laboratory and did not get a first-person experience how vague and vagarious can be a real work of an experimental scientist. Incidentally, as Alan F. Chalmers noticed, the same applies almost to all theoreticians of science [29]. Scientific research quite often consists in random, or slightly biased, search; scientific discoveries quite often arise by chance from a day and night drudgery. Serendipity is a most prominent feature of scientific progress, but it is conditioned

and circumscribed by the available instruments and techniques. The science of our days is less and less hypothesis-driven or concept-driven. Data-driven and instrument-driven (but also grant-driven or profit-driven) research is taking over. This change is just making more transparent the fact that the logic of scientific discovery has always been tightly tied to the logic of continually evolving instruments and corresponding techniques. It turns out that the Greek separation of theoretical and practical knowledge, of *epistemé* and *techné*, was an illusion.

Conscious reasoning, which was long considered to precede human action, may in fact appear after the action: awareness seems to be in service of subsequent rationalization of action (reviewed by Harth [30]). Humans, according to Elliot Aronson, are not rational, but rationalizing beings [31]. This principle may also apply to the description of experimental research: the majority of hypotheses may not initiate actions, but may be framed after the actions, to give the actions rational justification. It is the property of the human mind, perhaps rooted in the very neurobiology of the brain, that, by looking backwards, we ascribe consistency and logical sense to a complicated outcome of an evolutionary process full of trials and failures, contingencies and bifurcations. We may call this property the attribution fallacy. What the Danish philosopher Søren Kierkegaard declared of life, "Life is understood backwards but it is lived forwards" applies to all aspects of human understanding.

Both George Feher and Eric Kandel did they research by promptly exploiting all new techniques that were becoming available. This may well illustrate this "instrument logic" of the advancement of science. And since the advancement of science, by intermediary of politics and economy, is at the core of all progression of humanity, it seems that they are, at the very bottom of the causal hierarchy, scientific instruments and their intrinsic evolutionary dynamics that determine to where humankind is heading. Heading with ever increasing speed.

5. The ultimate stage of human evolution: *Homo artefaciens* turning into *Homo artefactus*

Anthropologists and other cultural scientists have extensively pondered on the role of initial artifacts in the evolution of culture. Some may have been used in religious rites, others in sexual display, still others as toys in social games. But in groups of hunters and gatherers the main function of artifacts was doubtlessly to serve at tools facilitating the provision of food. No less important were artifacts as arms. In all cases, simple artifacts were results of human intentions and served to predetermined purposes.

More complicated artifacts were gaining properties which had not been originally intended. An object designed for one function proved useful for other functions. Successful artifacts were copied, but also improved and innovated. Ever growing productivity of their manufacturing resulted in their exchange and gave birth to the market. Market exchange became one of the driving forces of innovation and invention of novel artifacts. As Leonard Read impressively depicted in his essay "The pencil", thanks to the market exchange thousands of people take part in the production of even such as a simple artifact as is the pencil [32]. Every new artifact differs only incrementally from its predecessor, but since the process is cumulative, very complicated objects are coming into existence on Earth. As an example, the jet plane Boeing 777 is assembled from three million precisely fitted parts [33].

Originally, artifacts served to satisfy those human needs that had originated in biological evolution. But new artifacts have gradually produced new human needs. Human dependence on artifacts has been evolving up to a state of addiction. The dynamics of evolution of artifacts is becoming ever more autonomous, independent of intrinsic human

needs and of intentions of their producers. Humans lose control over artifacts and are becoming more and more their servants, or even slaves. *Homo artefaciens* is turning into *Homo artefactus.*

This character of evolution of artifacts holds also for those that function as scientific instruments. In early phases of experimental science artifacts, manufactured for other purposes, were adopted as scientific instruments. Later, however, scientific instruments have become a novel, independent kind of artifacts. Peter Medawar, in a famous epigram, described science as "the art of soluble" [34]. In seems obvious that instruments determine what is soluble. We may add that what is not soluble lies behind the "Medawar's barrier". According to Richard Levins and Richard Lewontin, science advances in those directions where success is the greatest and the resistance to attain it the least [35]. Instruments may condition the trajectory. Success of a scientist is being appraised by two different criteria. First, according to the appreciation of the achievements by peers. Winning a Nobel Prize is generally seen as the highest recognition and may often be a major factor determining the choice of the subject of research. However, success of research is ever more gauged according to its practical impact: economy, the market, is becoming the main arbitrator of success.

Science is probably the fastest growing enterprise in our society [36]. Science is being transformed into technoscience. If, in the second half of the 20th century, there were some concerns that the state may monopolize science ("post-normal science"), nowadays corporations and private companies may ever more get possession of it ("post-academic science"). It is industry which decides to large extents the priorities of research [37].

At the same time, the dynamics of science, driven by scientific instruments, is such that the speed of generating new discoveries and inventions and of their application is increasing exponentially [38, 39]. They are indications that this growth becomes faster and has reached a hyperexponential, hyperbolic shape. Now, if a variable is growing hyperexponentially, it will reach infinity in a finite time. In mathematics, the point where the value of an otherwise finite and continuous function becomes infinite is called a "singularity". According to Raymond Kurzweil, technological singularity is imminent, it may be reached somewhere in the middle of the 21st century [2]. Artifacts are already superficially exhibiting some properties of living beings and we will hardly discern when they will get the capacity of self-replication and self-perfection.

This transformation of science may soon make human actors redundant and displace them from research. According to Hans Moravec (as referred in [40]) "we need a lot of engineers working diligently to make little improvements and then test them out in the marketplace". And Raymond Kurzweil maintains: "All that is needed to solve a surprisingly wild range of intelligent problems is exactly this: simple methods combined with heavy doses of computation, itself a simple process" [41]. Kevin Kelly writes that new tools will enable new structures of knowledge and new ways of discovery [42]. Robotics and computers will permit a brute force style of science: rapid automated exploration of all imaginable possibilities, with recurrent preservation of the best outcome, which would serve as an input for exploration at a new level.

These trends are quite conspicuous in molecular biology. On the one hand, problems are becoming exceedingly complex, defying human capacity of imagination and grasping. Even models of intricate networks of causations and interplays are becoming almost unintelligible. John Maynard-Smith already expressed his uneasiness [43]: "There is a danger that, in Boyd and Richerson's words [44], we shall replace a world which we do not understand by a model of the world we do not understand." On the other hand, an experimental biologist has to apply extremely complicated techniques to solve trivial and boring problems, such as a role of a specific nucleotide in a gene or a specific amino acid in a protein. A young novice in molecular biology, eager to approach great questions of life, the universe and everything, has

to learn enormous quantities of data to be eventually assigned to deal for months and years with such an apparent trifle. That is not enough. Soon will he/she be facing formidable competitors: robot scientists. In a pioneering study, Ross King et al. described a physically implemented robotic system that applies techniques from artificial intelligence to carry out cycles of scientific experimentation [45]. The system automatically originated hypotheses from all the knowledge of biochemistry stored in its large memory, devised experiments to test these hypotheses, physically ran the experiments using a laboratory robot, interpreted the results to falsify hypotheses inconsistent with the data, and then repeated the cycle. There was no human intellectual input in the designing of experiments or interpretation of data.

It becomes clear that cultural evolution, which succeeded biological evolution, has engendered another one: technoscientific evolution. Cultural evolution may have been a million times more rapid than the biological one. In turn, technoscientific evolution seems to proceed another million times quicker than the cultural one. Accordingly, the rate of evolution, since the entrance of the species *Homo sapiens* on the stage of life on Earth, may have accelerated 10^{12} times (Table 2).

Table 2. Types of evolution of life on Earth and its acceleration

Type	Duration, years	Relative median acceleration
Biological	4×10^9	1
Cultural	3×10^4	10^6
Technoscientific	2×10^2	10^{12}

It is remarkable how this evolution induces technooptimism in quite a number of people. Indeed, technooptimism may have been a lasting dominating ideology of scientists for quite a time. René Dubos believed that "by using scientific knowledge and ecological wisdom we can manage the earth so as to create environments which are ecologically stable, economically profitable, and favorable to the continued growth of civilization" [46]. Peter Medawar maintained that "science and technology are held responsible for our present predicament but offer the only means of escaping their consequences". With appropriate technology, he will be "completely confident of our ability to put and keep our house in order" [47]. Leonard Read in his famous essay on the pencil appealed: "The lesson I have to teach is this: Leave all creative energies uninhibited. Permit these creative know-hows freely to flow. Have faith that free men and women will respond to the Invisible Hand" [32]. Scores of other examples may be cited, expressing, explicitly or implicitly, a creed in human endless perfectibility.

This technooptimism has a fatal flaw. It completely ignores the fact that human animals are biologically constrained in acting, feeling and reasoning. What is limiting and is, in fact, insurmountable, is human nature, built in genes – it has not substantially changed in the course of some ten thousands years of cultural evolution. And obviously it could not be changed during a few decades of technoscientific evolution. On the other hand, the evolution of artifacts, including scientific instruments, has no ceiling, no limits, and humans apparently

have no means of how to curb it. “Makeability”, which may be boundless, does not equal “manageability”. Bertrand Russell saw it already in 1958: “At present, scientific technique advances like an army of tanks that have lost their drivers, blindly, ruthlessly, without goal or purpose” [48]. If this was the case in the middle of the 20th century, how much more it applies to the situation of humankind in the first decade of the 21st century! In addition, as Daniel S. Greenberg observed at the threshold of the new century, “The unfortunate, non-democratic truth is that science in the United States, and other nations, too, prospers in a state of disengagement from public understanding of the substance of science” [49].

6. Naturalization upwards: from molecules to biophenomenology

In his autobiographic overview George Feher explained the motivation behind his involvement in science by the following words ([4], p. 34): “It would, of course, be nice and noble to say that I pursued research in photosynthesis because it addresses the important questions of alternate energy source and food supply. But it wouldn’t be true. I have no pretension of being a do-gooder; I simply enjoy research and it fulfills an inner need. That it sometimes addresses a question of practical importance, and engenders support is fortuitous and lucky.”

Such a confession is a manifestation of intellectual honesty of a scientist. This is not to say that those scientists who claim that they have been motivated by their determination to serve humanity, or even to sacrifice their other interests to that goal, would be intellectually dishonest. Such motives may have been imprinted or imposed by conditioning upon them, without they being aware of it. It also might be a feat of rationalization, which takes place a posteriori and has been evoked in this essay in different contexts. The human being, a mythophilic animal, is a master of whole-hearted self-deception. But however selfish may be the motives of action of human individuals in their essence, humans objectively transcend their own biological selfishness by their work, by artifacts that result from the work. Mechanisms of human altruism have been recently much studied both theoretically and empirically. It is therefore rather surprising that there is yet not a single study which would focus on artefaction as an additional human-specific mode of altruism. Devotion to science, art, creative work in general, may even attain a self-destructive character. However, also in the case that creative work brings advantages for a creative individual, for instance as a gain in Darwinian fitness, its beneficial effect for other people may be much more extensive and far-reaching.

The problem is that what is true of benefaction is also true of malefaction. We would wish that science provides us energy for illumination, heating, and driving our cars, but not for bombs; that airplanes serve tourists but not terrorists. This, however, is impossible: there is no axiological asymmetry built in science; science is indifferent towards both Good and Evil. Not only technooptimism appears to be naive, but also the lasting sermons of how science is a unique blessing for humanity and how it will eventually remove all human troubles and bring forth a perfect world. No one has yet proved that the number of new problems that science has generated is smaller than the number of problems it had solved.

This is why no conclusions can be drawn from the analysis presented in this study that might be of use for reformers, visionaries and saviors. The study does not line up with the neoenlighteners among scientists, who pledge their allegiance to the Enlightenment creed in the power of the individual human reason, in the possibility of indefinite human progress and in unrestricted human malleability. But if the indulgence in the naive optimism appears futile and misleading, does it mean that the only other option for creative minds, the tiny minority within the Great disparity, would be resignation and fatalism? Even more so, if science is

turning into technoscience, if refined instruments are displacing human actors from research, if research problems are becoming prohibitively complicated or, in reverse, trivial and uninterested. As if the opportunity, which George Feher encountered in his life, to "simply enjoy research" which "fulfills an inner need", were also fading away.

It seems that the state of humankind upon the entrance into the 21st century brings us back to the essential questions which humans have been asking for centuries. To the questions that were the questions of philosophy and may now, with ever more sophisticated instruments in hands, become the questions of science. They may represent a novel intellectual challenge *par excellence.* According to Alfred North Whitehead, "The safest general characterization of the European philosophical tradition is that it consists in a series of footnotes to Plato" (quoted in [50]). The time has come to end with footnotes to Plato's writings. It has been already argued why traditional European rationalism and humanism should be replaced by evolutionary rationalism and evolutionary humanism [22]. In the endeavor that may be dubbed the "naturalized philosophy", it may turn out that some very basic questions of European philosophy were framed in a wrong way, and some of its fundamental concepts, such as infinity, eternity, immortality, duality of body and mind, trinity of Truth, Good and Beauty, were meaningless. It has been said repeatedly that the "theory of everything", so tenaciously searched for by the contemporary physicists [51, 52], may turn out not to be the final theory of the fundamental elements of the world but the theory of the mind and of its relation to the universe.

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