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**DISCUSSIONS**

# Ontology Paradigms

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**Abstract**—The technologies for biophysical insights are briefly reviewed. These technologies correspond to different methodological paradigms and are regarded as different linguistic forms of knowledge.

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Modern epistemology has various points of view on the methodology of the development of science. I plan to confine myself to two aspects. On the one hand, Thomas Kuhn in his monograph *The Structure of Scientific Revolutions* [1] grounded the thesis of a stepwise methodology in the development of science: new concepts make paradigm revolutions in the monotonic process of scientific knowledge accumulation, making it necessary to revise the conceptual foundations of an established science. Here is the simplest illustrative example: once Max Planck introduced the new physical concept of the "quantum" a novel physics of elementary particles, quantum mechanics began to develop. Another aspect of the scientific epistemology is expressed by the well-known saying of Dmitry Mendeleev that science begins with the beginning of measurements, i.e., when the volume of accumulated quantitative data is enough for their mathematical analysis focused on revealing theoretical patterns and new theoretical concepts.

The history of science has examples in which new concepts emerged earlier than the corresponding adequate measuring tools; in such situations, theoretical revolutions were "delayed" while waiting for their experimental grounding. As an example, the theoretical concept of mechanical "energy" dates back to Aristotle, who formulated it as "the ability of a body to continue its movement and do work"; however, it took centuries for physics to experimentally substantiate the basic meaning of this concept by using both mechanical and thermodynamic measurements for this purpose. Aristotle tried to describe and understand thermodynamic phenomena utilizing the qualitative concepts of "heat and cold": he clearly needed an as-yet absent concept, that of "temperature." The emergence of this concept became possible as soon as the corresponding measuring tool, the thermometer, was invented.

Kuhn confined himself to distinguishing only conceptual (i.e., theoretical) scientific revolutions that arise from new concepts. However, in my opinion, the experimental revolutions induced by new measuring tools are no less important for the emergence of new scientific paradigms. In particular, this implies that the physics of elementary particles ceased advancing because it reached the limit of measurement possibilities. On the other hand, the measurement capacity of biophysical systems is still inexhaustible, thereby making the potential development of this science inexhaustible.

In addition, Kuhn evades the causative aspects of the changes in scientific paradigms; however, analysis of the historical cases allows the following hypothesis to be suggested: the reformatory ("revolutionary") stages in knowledge acquisition are determined by a constructive worldview, which rests upon the accumulated experience in descriptive concepts that prepare the possibility of more-adequate theoretical reconstructions.

The systems-based organization of nature, animate and inanimate, allows manifold informational technologies to be used for gaining insight into its existence utilizing various methods for knowledge representation (descriptive, analytic, and synthetic). These methods correspond to different epistemological paradigms, as well as different ontologies, because they reveal different entities of the studied objects and the subjects that perform the study.

## THE PARADIGM OF THE OBSERVER

As is known, any insight into natural phenomena and objects starts with observations and subsequent descriptions of observation results, which are further ordered, systematized, and classified. The primary descriptive knowledge acquisition was characteristic of the early antique science and Plato's epistemological philosophy [2]. The general principle for this type of gaining knowledge is briefly described by the following linguistic formula of the paradigm of the Observer:

"I know that which I can describe."

The general task of descriptive knowledge acquisition is the linguistic fixation and documenting of sensory ("perceptible") impressions and concepts identified with facts as well as the thoughts ("arguments") that accompany the observations (hypotheses, heuristics, speculations, opinions, and fantasies). Note that, on the one hand, various languages developed thanks to the solution of these descriptive tasks and, on the other hand, different ethnic groups "grew wiser" to different degrees thanks to this linguistic progress. It is reasonable to assume that the level of linguistic culture of a nation represents the basic level of its total humanitarian culture. The current European languages are the most developed because they possess a tremendous semantic capacity that allows the discussion and understanding of any humanitarian and scientific–technological issue, including logical paradoxes that are irresolvable by formal tools, or, for example, for discussion of the mathematical nature of Gödel's incompleteness theorems and a search for novel methods to overcome these difficulties.

We recently discussed the structure of written Chinese at a seminar and quite unexpectedly noted that there were no hieroglyphs for jokes. This brings about the natural inference that the Chinese people know how to enjoy life but are unable to joke and raises the question on whether it is essentially important for scientific and technological progress to be able to joke and, in general, to have a sense of humor. The ancient Chinese culture is famous for many technological innovations. Consequently, technological creativity does not require any sense of humor. However, Chinese have not contributed to the theoretical science, metaphysics, while the Ancient Greeks, with their evident sense of humor (see texts by Aristotle that contain various jokes) were more successful in this abstract area.

## THE PARADIGM OF THE ANALYST

A stricter formal language of logical conclusions was initially formed in the context of systematizations of the methods for solving mathematical problems. It then became more widely used in clarifying the semantic and logical links between nonmathematical concepts, such as ethics and esthetics. The attempt by Pythagoreans to instill mathematical concepts with an ontological status ("everything is number") initiated the creation of a novel analytical methodology for studying nature, which was later referred to as the "scientific" methodology.

Aristotle was the first task-oriented developer of scientific methodology in the spirit of the paradigm of the Analyst [3], who introduced a new ontological principle, namely,

"I know that which I can prove."

As is known, Aristotle at first comprehensively elaborated *logic*, the science of reasoning that comprises deductive and inductive methods. Note that the initial stimuli for the creation of *logic* and *analytics* were, on the one hand, the discussions with sophists and, on the other, Socrates' dialectic method of inquiry is based on a series of questions, whose answers via successive generalizations gradually distill the final conclusion or, in other words, the truth. The motivation for the creation of the subsequent treatises: *Physics, Metaphysics, On the Sky, On the Soul*, and others, is also interesting; as I see it, these treatises should be interpreted as examples of the first conceptual understanding of physical and biological entities within the new analytical paradigm. When creating *logic*, Aristotle realized the natural-science universality of analytical methodology: if the method of suggestive questions and successive generalizations is used not only, say, in court procedures in order to establish a juridical truth, but also aiming to clarify a scientific truth, the result will be logically substantiated knowledge about natural entities, principles (axioms), and consequences (laws). The logical and analytical methodology of Aristotle is the particular factor that gave birth to the scientific approach that is currently referred to as the "systems" approach, which is stated at the very beginning of his *Physics*:

"When the objects of an inquiry, in any department, have principles, conditions, or elements, it is through acquaintance with these that knowledge, that is to say scientific knowledge, is attained. ... The natural way of doing this is to start from the things that are more knowable and obvious to us and proceed towards those that are clearer and more knowable by nature; for the same things are not 'knowable relative to us" and "knowable" without qualification. Thus, in the present inquiry we must follow this method and advance from what is more obscure by nature, but clearer to us towards what is more clearer and more knowable by nature. Now what is to us plain and obvious at first is rather confused masses, the elements and principles of which become known to us later by analysis." (translation by R.P. Hardie and R.K Gaye, Oxford, Clarendon Press, 1930).

To be brief, the natural way of acquiring scientific knowledge runs from the whole to its elements and axioms and only then from the axioms of elements to the whole. Indeed, this way has turned out to be natural for the further development of both physics and other fields of science.

Note here that the term "principles" in the natural-science treatises by Aristotle is a synonym of the term "axioms," as initially introduced by Aristotle himself; however, it is explicitly defined only in the treatise *Posterior Analytics*, stating that axioms are basic propositions used for proof. Thus, the systems approach of Aristotle is an axiomatic approach in its essence. This name became basic after this method was, most likely, used for the first time by Euclid for his presentation of geometry.

## THE PARADIGM OF THE PHYSICIST

The special category of scientific knowledge determined by either the choice or discovery of measuring instruments formed in the spirit of the paradigm of the Physicist:

"I know that which I can measure."

The basic concepts in the category of measurable terms are length and time: the corresponding tools are rulers and clock. Aristotle knew only three types of clock, the sundial (gnomon), the sandglass, and the water clock (clepsydra). The existence of different clock types suggested the feasibility of using different reference motions: of the sun, sand, and water to measure the same time span:

"Time is a measure of motion and of being moved; it measures motion by determining a motion that will measure exactly the entire motion, as the cubit does the length by determining an amount that will measure the whole. Further "to be in time" means for movement, that both it and its essence are measured by time (for simultaneously it measures both a movement and its essence, and this is what being in time means for it, that its essence should be measured)." (translation by R.P. Hardie and R.K Gaye, Oxford, Clarendon Press, 1930).

The scientific revolutions associated with space–time measurements are well known, and the first of these revolutions was made by Nicolaus Copernicus.

The second revolution in both astronomy and mechanics was made by Tycho Brahe and Johannes Kepler. It would be no exaggeration to say that they did it together, Brahe as an outstanding experimenter and Kepler as an outstanding theoretician. Brahe reached the highest accuracy in astronomic observations by the unaided eye. Amazingly, this accuracy appeared sufficient for Kepler to prove the ellipticity of the trajectories of the planets. Further invention of the telescope soon after Brahe's death radically but not immediately changed the astronomical practice: seamen used Kepler's tables, containing the future coordinates of planets for 200 years ahead, to the very end of their forecast, i.e., for 2 centuries.

The third revolution in physics, relativistic revolution, is also associated with space–time observations. It has emerged that the use of radar for measuring distances instead of solid (Euclidean) rulers, i.e., the measurement of distance by the time a signal goes back and forth, gives a new chronogeometry, as discovered in 1908 by Hermann Minkowski. The relativistic problem has a biomechanical extension. When we walk, our brain also solves the problems of matching the events in two reference systems, the body and external space [4].

Archimedes initiated the establishment of experimental physics based on measurements and Galileo continued this process. Variation of experimental conditions is the main revolutionary idea of Galileo, which eventually led him to his discovery of the laws of falling bodies. The invention of new measuring tools, the thermometer and barometer, is also associated with the name of Galileo. Further improvement of these tools enhanced the establishment of the scientific concepts of temperature and pressure, which became the basic theoretical references in thermodynamics. The methodology of instrumental measurements became the basic paradigm of the new physics and all its new areas: thermodynamics, optics, electrodynamics, and atomic physics.

Chemistry began to adopt the measurement technologies of physics, thereby enhancing the revolutionary transformation of chemical research. The current biophysics was also formed primarily on the experimental wave by introducing physical measurements in biology, including electron microscopy, electrophysiological measurements, and 3D reconstructions of macromolecules.

## THE PARADIGM OF THE CONSTRUCTOR

When writing my Doctor of Science dissertation [5], I grasped that it would be helpful to distinguish one more ontological principle in the spirit of the paradigm of the Constructor:

"I know that which I can construct."

Does the construction principle represent a specific type of knowledge? In his *Metaphysics*, Aristotle used the character of a building constructor and refers to his knowledge as "experimental." Aristotle then opposed experimental knowledge to the knowledge of a theoretical physicist, who comprehends the "causes" and "essence" of reality rather that only material "forms" of this reality. However, the constructive or, in other words, engineering activities of a human being are not confined to material production.

Indeed, theories also have to be constructed. Theoretical trends in constructive methods have deep roots that naturally originate from physics. Presumably, Isaac Newton was the first theoretical constructor in physics: he reconstructed the dynamics of celestial mechanics by using the kinematic laws of Kepler and Galileo's experimental data as invariants of nature. Newton himself referred to his reconstruction as "theoretical physics." Leonhard Euler took up the baton from Newton by starting to elaborate the analytical tools of classical mechanics. Later, Jean-Baptiste d'Alembert, Joseph Lagrange, Pierre Laplace, and many others joined this creative process. New planets were predicted and discovered on this wave of theoretical enthusiasm. The new revolution in physics started when James Maxwell reconstructed electrodynamics based on the experimental data by Michael Faraday and Heinrich Hertz predicted and proved the existence of radio waves using Maxwell's theory.

I will not list all the outstanding advances in physics. Acting as an opponent to Kuhn, I simply want to illustrate my thesis that the revolutions in science occurred not only and not so much owing to new concepts, but also because of the advent of new methods, methods of measurements in experiments, and methods of reconstruction in theory. In the 20th century, physics reached the experimental limits of measurability; this refers, on the one hand, to the modern theories of elementary particles and, on the other, to the astrophysical concepts of "black holes" and the "expanding Universe." The method remains but the substrate for basic research has disappeared. The physicists have exhausted all measurable physical entities over 3 centuries of collective genial efforts, have not they? It looks as if only applied nanotechnologies and very expensive toys, synchrophasotrons, are left for physicists. What are physicists to do further? There are not enough synchrophasotrons and nanotechnologies to go around.

It is timely to recall that Aristotle established Physics as the science of *Nature*, inanimate and animate, i.e., as *Biophysics*. The physicists dealing with inanimate nature have left the physicists dealing with animate nature behind only because the former turned out to be simpler. Thus, since "inanimate physics" is successfully over, it is high time to switch the attention to "animate physics" with its long-lasting reserve of basic problems.

One of the problems is whether the brain is a computer or a constructor.

In my opinion, the second variant is more meaningful, because the brain constructs the speculative and conceptual models of the surrounding world using the overall set of sensory systems as the information channels. It is now clear that, for example, the visual image of the outer world is constructed in our consciousness via mental modeling and the final virtual model corresponds to the real world. In particular, this follows from the experiments with the glasses that give an inverted image of the outer world. The basic task in spatial mental modeling is the formation and navigation of two reference systems associated with one's own body and the environment. Undoubtedly, the problems of forming coordinate bases and coordinate motor control belong to the class of construction problems, since they are redundant in the degrees of freedom and considerably variable in the configuration and dynamic conditions for arbitrary and locomotor movements.

The basic significance of constructive biotechnologies becomes evident when analyzing the events of embryogenesis and ontogenesis. Broadly speaking, the controlling information machine of these events is the genome, acting as a Constructor (or Engineer?) of cells and, possibly, a multicellular organism. Can we say that the genome "knows" what it does? A negative answer is obvious in this case because the problems associated with the awareness of knowledge are solved by the specialized "cognizing machine," the human brain. Another statement of the question is of interest: what should the brain know to be able to understand and imitate the functions of the genome? The state-of-the-art molecular genetics actually tackles this particular problem, since constructive scientific knowledge should correspond to the constructive ontology of the genome. Presumably, only the human brain possesses a special intellectual ability to comprehend any piece of knowledge, even that concealed in the subconscious and intended for the performance of many "nonintellectual" control functions that are characteristic of animals as well.

As for the technical activities of humans associated with building construction and manufacture of various machines: mechanical, thermal, chemical, electric, and computing activities, the necessary knowledge for this purpose may be regarded as applied or technical, characteristic of engineering creative work and technical thinking. However, the constructive applied knowledge also has its basic, i.e., theoretical, component, which is as yet poorly studied. The case is that the role of scientific methodology in constructive ontology is played by technologies, which comprise the problems of coordination of multiunit and multiparametric processes that underlie production and assembly. The advance in computer-modeling methods, in particular, the systems of automated design and methods of artificial intelligence, brought about significant progress in the understanding of such problems.

## THE PARADIGM OF THE PROGRAMMER

The modern tools for computer simulation, including the object-oriented programming technologies, create fundamentally new possibilities for the development of constructive ontology, first, of a virtual type, for example, for studying and optimizing a model technological process, and, second, of a real type, for controlling a real manufacturing process. Moreover, almost the entire formal natural-science knowledge represented in a mathematical form is gradually undergoing software coding and modeling. Computer linguistics makes it possible to combine analytical, i.e., computational, methods with logical and constructive methods, as well as graphical representation and animation. This makes the forthcoming virtual ontology in the spirit of the paradigm of Programmer topical:

"I know that which I can code."

Currently, the problems that are relatively easy for a human to solve remain the most difficult and unsolvable for computer intelligence, for example, the problems of semantic analysis and understanding of texts. I will omit considering various aspects of human creative activities that are beyond the reach of a computer in principle and only mention one reference. Aristotle distinguished the possibility of passing knowledge from teacher to pupil as one of the characteristic properties of knowledge. Note that a gifted teacher is able to teach an uneducated pupil many things but cannot teach anybody to create, since any creative work is individual and unique. In addition, a creative person does not know himself why and how he creates. Thus, it is a fool's errand to train a computer to do creative work.

So, what is the Knowledge that can be passed and taught?

First, the task of Knowledge transfer is not equivalent to information transfer. Information is transferred in a computer in a very simple manner by rewriting files from a disk of one computer to a disk of the other. In this process, the "computer knowledge" is transferred together with the software product. However, it is impossible to analogously rewrite knowledge from the brain of a teacher to the brain of a pupil. The traditional and ancient method is to pass knowledge either orally (as a lecture or a dialogue) or in a written form (textbooks). It is necessary in both cases that the pupil would understand the teacher, which is feasible only when their associative spaces are a type of isomorphic space. This is typically possible in universities. As for a common school, especially primary school, a pupil typically does not understand a major part of the new knowledge passed to him by a teacher. Is this a deadlock? Yes. The way out of this semantic deadlock lies in the activity of the pupil. First, the pupil "mechanically" memorizes the obtained information as a kind of "linguistic music" to further rehearse this music in different variants in order to pick out an invariant melody or semantic synergy, which is more adequately referred to as an informative thought.

Pupils are best at learning the rules and methods that rather represent syntactic and technological pieces of knowledge that make it possible to construct standard examples of variants and distinguish between variable and invariant associative links.

Conclusion: the transfer of knowledge is impossible without self-apprehension of the received information and without unaided independent revelation of its content.

Note that a person follows the same pattern when learning new movements, for example, dancing (to some music), by repeating the shown movements until he himself solves the coordination problem, i.e., until he "programs" a new synergy.

The overall, so to say, formal knowledge, including mathematics and mathematical sections of physics, chemistry, and biology, is mostly syntactic and technological knowledge. This is the reason that we have succeeded in "teaching" computers this kind of knowledge.

The current computer interpretation of living systems brings forth new aspects of constructive ontology. When creating a humanlike robot within a standard computer metaphor, we, acting as a *Constructor*, comprehend a large amount in principle from the perspective of simulated control, for example, what software is necessary for simulation of motor functions, even rather complex ones. A significantly more difficult problem, which still has no solution, is simulation of a spoken dialogue between a computer and a human. Many readers may recall Alan Turing's test in *Can A Machine Think* [6]. Interestingly, René Descartes when developing his original concept of "human–machine" also tried to find the answer to this question. The only difference lies in the fact that Descartes had no idea of a machine corresponding to a human (or animal), while Turing meant a computer, and not even only the quickest computer but a certain universal computer program (the Turing machine).

## THE PARADIGM OF INTELLIGENCE

Both computers and software tools have radically advanced over the half century after Turing. Moreover, Turing's test initiated the development of a specialized information technology focused on the creation of "artificial intelligence." Nonetheless, significant intellectual efforts of developers and tremendous financial expenses of customers have failed in teaching computer to think. Why? Because the issue of what should be taught to a computer to make it able to think is still vague. Thus, we ourselves do not understand what it means to think, i.e., we do not know the ontology of thinking in the spirit of the paradigm of Intelligence:

"I know that which I can understand."

The "joke" by Descartes, "I think, therefore I am" ("*Cogito ergo sum*") [7], is well known. Some philosophers seriously believe that this paradoxical phrase initiated the development of "cognitive psychology." However, in my opinion, this phase is incorrect from the standpoint of ontology. There, "my thought" acts as the primary identifier of "my existence," while, all joking aside, "my existence" is the necessary condition for "my thinking" and thinking is necessary for understanding not only the fact of my existence, but also the existence of my consciousness and the outer world not connected with my cognitive capacity.

Generally speaking, a thought is a linguistic product or a linguistic tool that is necessary for a semantic analysis of the "meaning of being" and understanding of other people, for example, for the sake of their happiness and wellbeing.

The first fundamental task on the path to "computer intelligence" is to teach a computer to understand texts written by humans. Once this problem is solved, the computer will become a "faithful friend of man," competing with the dog. However, this is not yet the step where we will be able to teach a computer to think. In my opinion, the next necessary step is to teach a computer to understand jokes. In solving this problem, we should not use Chinese texts (as mentioned above) but rather English (English humor is more brilliant than oriental wisdom) or Russian (Russian jokes have always strengthened the critical spirit of the nation).

Once the computer acquires a sense of humor, it will learn to think for itself.

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